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TELECOMMUNICATION

COMET AND CLOSE-APPROACH ASTEROID MISSION STUDY

FINAL REPORT

VOL. 6

CONTRACT JPL 950870

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

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PHILCO CORPORATION
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Prepared for
Jet Propulsion Laboratory
Pasadena, California

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WDL DIVISION

FOREWORD

This document is the final report of work performed on Telecommunication by the WDL Division of the Philco Corporation during the Comet and Close-Approach Asteroid Mission Study for the Jet Propulsion Laboratory under Contract JPL 950870. The report covers work performed during the period 2 July 1964 to 2 January 1965.

ACKNOWLEDGMENT

This volume was prepared by Herman Bustamante with a contribution by William Slivkoff to the Microelectronics section.

SUMMARY

ABST

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The primary objective of this study was to provide a communication system design that would satisfy the needs of several comet and close-approach asteroid mission. In doing this it was intended that the system be as reliable as possible. With this in mind Mariner-C communication hardware was considered first for use on this mission. Several of the components can be used just as they are, e.g. the transponder and command detector. New equipment consists of 25-watt amplifiers, the television optical system, processing equipment for the scientific instrumentation, the tape recorder and the low wise-figure pre-amplifier. The rest of the equipment consists of modified Mariner-C hardware. The recommended system is described in Section 2.

In arriving at this system design, these analyses were performed. A mathematical analysis, presented in Appendix 9, was performed to define the transmitter power-antenna gain requirements versus range and data rate. These capabilities were then compared to the data transmission and data collection requirements for a typical comet probe scientific package and command system (Sections 3 and 4). Adding to this the antenna coverage requirements (discussed in Section 5) lead to a complete definition of the communication system. Based on these requirements, an evaluation was performed of the best system implementation. The result is the recommended system.

AUTH OR

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SECTION 1

OBJECTIVES AND REQUIREMENTS

1.1 GENERAL CONSTRAINTS

In arriving at an optimum system, the selection of configurations and hardware must be guided by an evaluation of the effects of this selection upon the total spacecraft design. The system must be designed with a capacity or growth potential for transmitting and receiving data on missions to several comets of interest and to selected close-approach asteroids during 1967-1975.

The spacecraft operates with the DSIF as described for the years 1964-1968 [JPL, 1964]. The availability of the 210-foot dish at stations other than Goldstone is uncertain; hence the 210-foot is assumed to exist only at Goldstone. It is desirable to utilize as much flight-proven, reliable hardware as possible; thus capabilities of Mariner-C hardware are considered.

1.2 SYSTEM REQUIREMENTS

In addition to these general constraints, the basic requirements of the telecommunication system are as follows:

a. A telemetry subsystem to store and transmit all information gathered throughout the flight.

b. A command subsystem to initiate events, to backup the CC&S-initiated commands, and to adjust the automatic on-board sequencing of mission events.

c. A ranging subsystem to establish the spacecraft trajectory and to correlate collected data with the spacecraft's coordinates in space.

SECTION 2
TELECOMMUNICATION SYSTEM

2.1 OVERALL SYSTEM

The recommended system is described by the block diagram shown in Figure 2-1. PN synchronizing techniques with PSK modulation are used to maximize the total amount of proven hardware and [illegible] efficient modulation technique. Table 2-1 below is a tabulation of major hardware indicating which is Mariner equipment and which is [illegible] for a minimum-modification system.

Switching is provided for the telemetry transmitter [illegible] either the high-gain antenna or the omni. The power [illegible] drives the antenna in all cases. This minimizes coverage requirements for the high-gain antenna by utilizing the wide coverage [illegible] the omni during the near-earth portion of the flight. [illegible] at both [illegible] watts and 25 watts are indicated. [illegible] depends on the operating range requirements of [illegible] mission and on the data rate requirements.

Examination of the system diagram indicates only two [illegible] in the overall system as compared to the Mariner-[illegible] system: (1) [illegible] amplifier has been inserted prior to the transponder, [illegible] of command signals via the high-gain antenna is not [illegible] pre-amplifier provides a decrease in system noise [illegible] 7 db which permits adequate reception out to a range of [illegible] to 200 million miles (160 to 320 million km). This is sufficient to satisfy all missions and eliminates the need for switching to the high-gain antenna at the extreme ranges. The system is considerably more reliable at a cost of only 1 pound and an insignificant amount of power for the pre-amplifier.

Table 2-1 Communication Hardware for Minimum-Modification System

COMPONENT	SOURCE
Transponder	Mariner
10-watt Power Amplifier	Mariner
25-watt Power Amplifier	New: Raytheon-Amplitron Watkins-Johnson - TWT
4-foot Antenna	Modified Mariner
6-foot Antenna	New: Hexcel-Honeycomb
Ranging Module	New
Command Detector	Mariner
Command Decoder	Modified Mariner
Data Encoding and Storage	Modified Mariner and New Proven Equipment
Tape Recorder	Possibly Mariner
Pre-Amplifier	New
Omni Antenna	Modified Mariner
Computer Sequencer Programmer	Modified Mariner

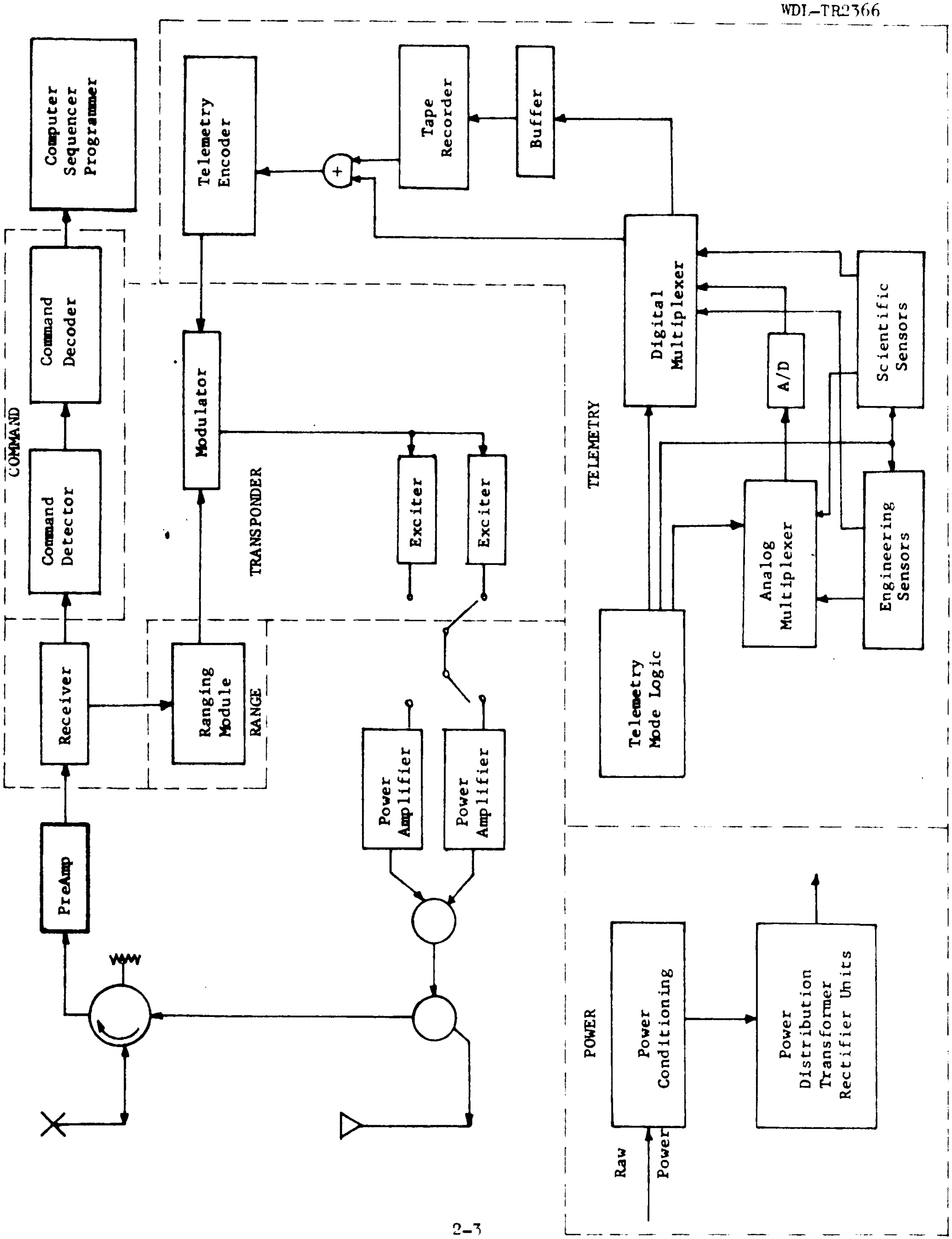


FIG. 2-1 Spacecraft Telecommunication Subsystems

Table 2-2 Communication System Hardware Characteristics

TEMP. LIMITS (°C)	COMPONENT	WEIGHT POUNDS	POWER WATTS	VOLUME CU. IN.	SOURCE
-10° +75°	Transponder	11	15.0	575	Philco
0° +50°	10-Watt Power Amp.	10*	40	180*	JPL - Cavity Hughes - TWT
0° +50°	25-Watt Power Amp.	15*	65 to 100	300	Raytheon-Amplitron or WJ - TWT
+65°	4-Foot Antenna	7	----		Hexcel-Honeycomb
+65°	6-Foot Antenna	10	----		Hexcel-Honeycomb
-10° +75°	Ranging Module	6	3		Philco
-10° +75°	Command Decoder	4	3	90	Philco
-10° +75°	Command Detector	4	2	90	Philco
-10° +75°	Data Encoding & Storage, Data Processing	25	15		
-20° +50°	Tape Recorder	8	7	300	Raymond Engineering Laboratories
-10° +75°	Pre-Amplifier	1	0.05	20	Microstate
	Omni Antenna	4	----	----	Philco
-10° +75°	TR Units	10	16		

* 2 Units

2.2 MICROELECTRONICS AND PACKAGING

Assuming a minimum of modification is desired, the units used for the receiver, exciter, command detector, ranging module, power distribution system and telemetry subsystem building blocks are those of the Mariner. This, however, may not be the optimum system since it does not take advantage of micro-element components and the better packaging techniques now available. Whereas Mariner-C hardware is welded cordwood construction. the state-of-the-art in micro-element logic is such that all of the digital circuitry and a good portion of the analog circuitry can be converted to micro-elements presently on the market. Table 2-2 presents a tabulation of hardware characteristics.

A high percentage of the circuitry in the command detector can be digital. Only the filter circuitry, some amplifiers, and some of the chopper circuitry are not convertible immediately to off-the-shelf micro-element circuits. The savings in weight of the unit is estimated conservatively to be 35%, the cost of the detector will be cheaper and the intrinsic mean-time-to-failure of the unit will be improved. These estimates are based on Philco WDL experience in building micro-element systems and also on the results of an in-house study effort consisting of a thorough evaluation of micro-elements on the market in terms of electrical operating characteristics, packaging techniques, and the size, weight, and cost of discrete component circuits.

An example of improved packaging techniques now available is the S-band transponder that Philco WDL has been producing for JPL. The original JPL S-band unit has been redesigned in an attempt to minimize size and weight. The final design has identical electrical charactertistics but has been reduced by more than 50% in size and weight. A detailed application of microelectronics to the Comet Probe telecomminication system is presented in Section 6. The results of the in-house study effort mentioned above are outlined in Appendix B.

2.3 ANTENNAS

The antennas recommended for use on the Comet Probe are similar to those used on Mariner-C and built for JPL by WDL. The omni-directional antenna should be modified. The omni provides adequate but not optimum performance; with a few minor changes its performance can be improved. The recommended design changes not only will make the antenna a better-performance unit but a simpler and cheaper unit as well. The basic Mariner-C omni antenna design was selected not because the unit is available, but because it is well-suited to provide the wide-angle coverage required with a simple structure.

The high-gain antenna to be used depends on the comet selected on the intercept range, and on the probe's angular distance above the ecliptic plane. This angular deviation is important during those phases of the mission that depend on the high-gain antenna for telemetry transmission. If the probe remains in the ecliptic plane throughout its flight, a pencil-beam antenna has to be repositioned only in one plane, i.e., the ecliptic plane. On the other hand, if the probe travels out of the ecliptic plane, a pencil beam has to be repositioned not only with an angular motion parallel to the ecliptic plane but perpendicular to it as well. The use of a fan-shaped beam reduces the antenna pointing requirements, since now the receiver can move an angular distance equal to the width of the fan beam before the antenna has to be repositioned. These considerations are discussed in Section 5 and the pointing requirements for several of the comets are shown in detail for the entire mission.

SECTION 3
COMMAND SUBSYSTEM

3.1 SUBSYSTEM REQUIREMENTS

PCM/PSK/PM modulation with PN code synchronization is recommended for the command system. The single-channel system conceived by JPL and illustrated in Figure 3-1 has been shown mathematically to be the most efficient system of the types that have been implemented. The commands required on comet missions are comparable in number and type to those required for the Mariner Mars spacecraft. The number of commands is somewhat larger because of two midcourse corrections and encounter comet acquisition, verification, and tracking functions. These functions make the command system a necessity rather than a backup system during the encounter.

In Appendix A an analysis of link capability and power requirement is performed. These calculations assume fixed system parameters. However they can be used as a basis for calculating actual system capabilities. As the antenna gain varies in time due to the continuously changing orientation of the spacecraft with respect to the earth, the system cpaability changes. Taking this into account, the power requirements for the command link have been calculated and are presented in Figures 3-2 to 3-5. The assumptions for these curves are the use of the DSIF 85-foot dish, the response of the Mariner-C omni antenna, a 1-bps transmission rate, and a 4-db noise figure pre-amplifier in the spacecraft receiving system.

3.2 COMMAND CAPABILITY

Table 3-1 below includes a tabulation of the power requirement and system capability of the command link at intercept and at 30 days after intercept.

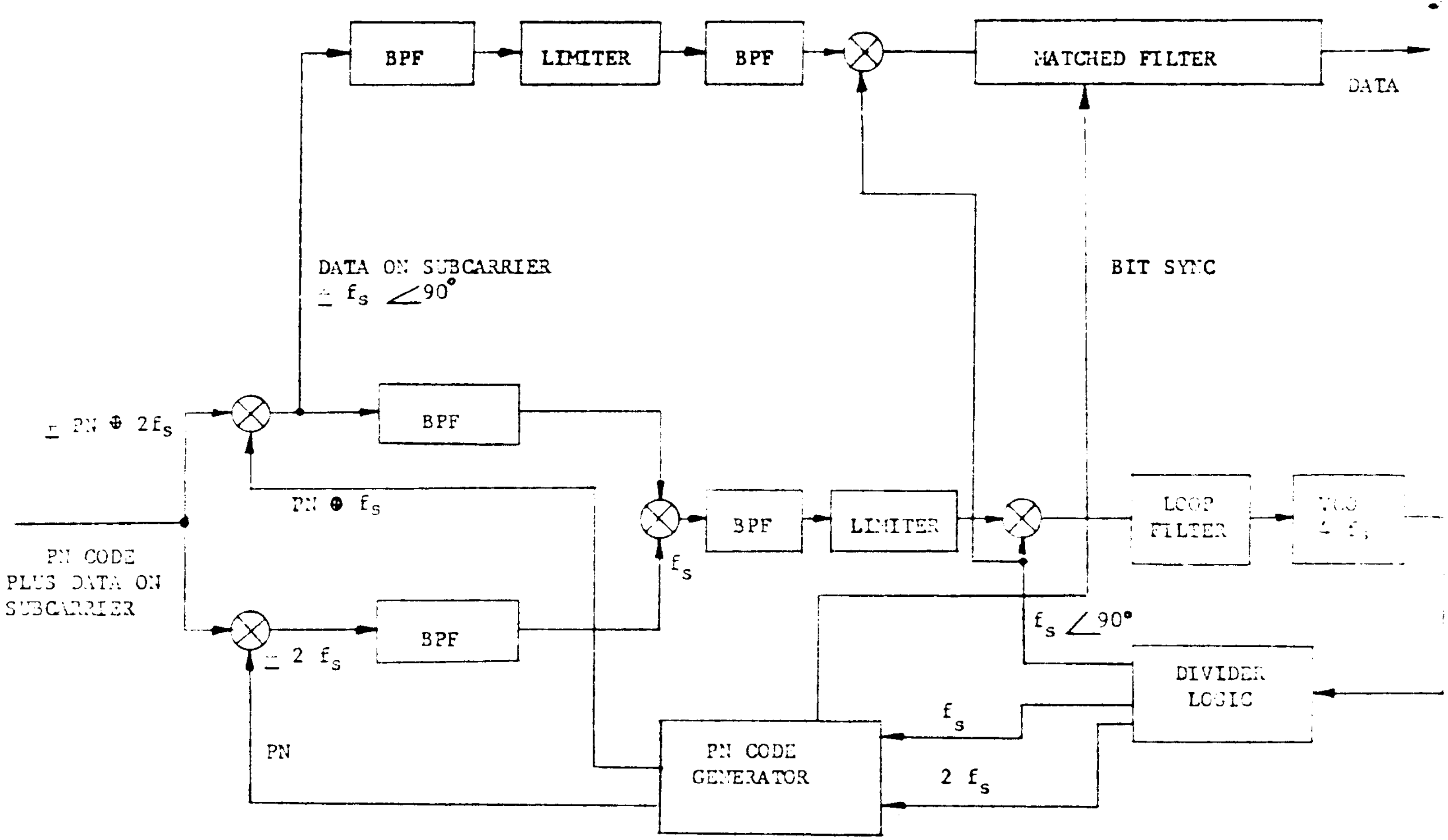
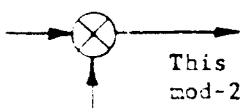


Fig. 3-1 Single-Channel PN-PSK Detector


This symbol represents a phase detector, mod-2 adder, or multiplier as required.

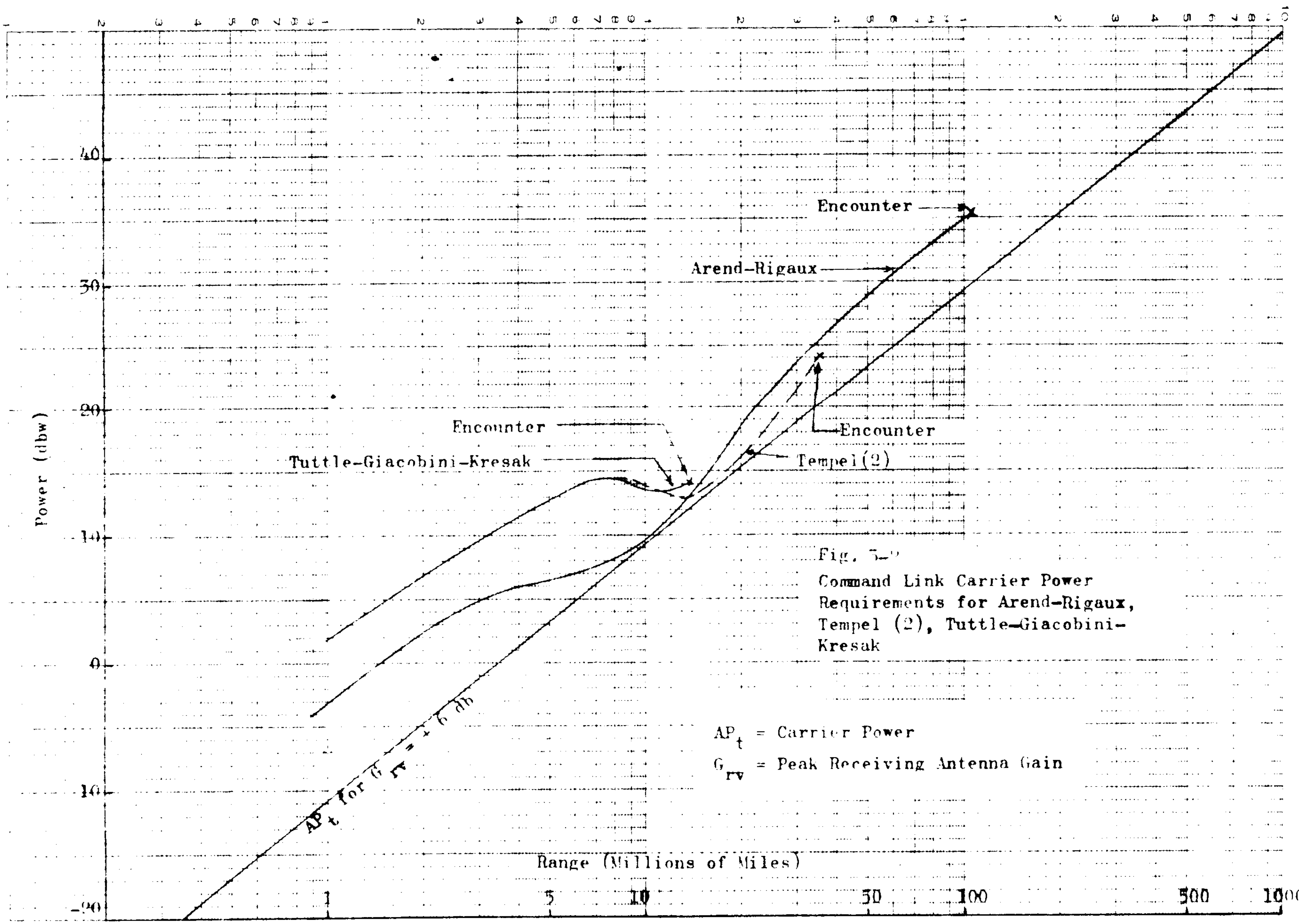


Fig. 3-?
Command Link Carrier Power Requirements for Arend-Rigaux, Tempel (2), Tuttle-Giacobini-Kresak

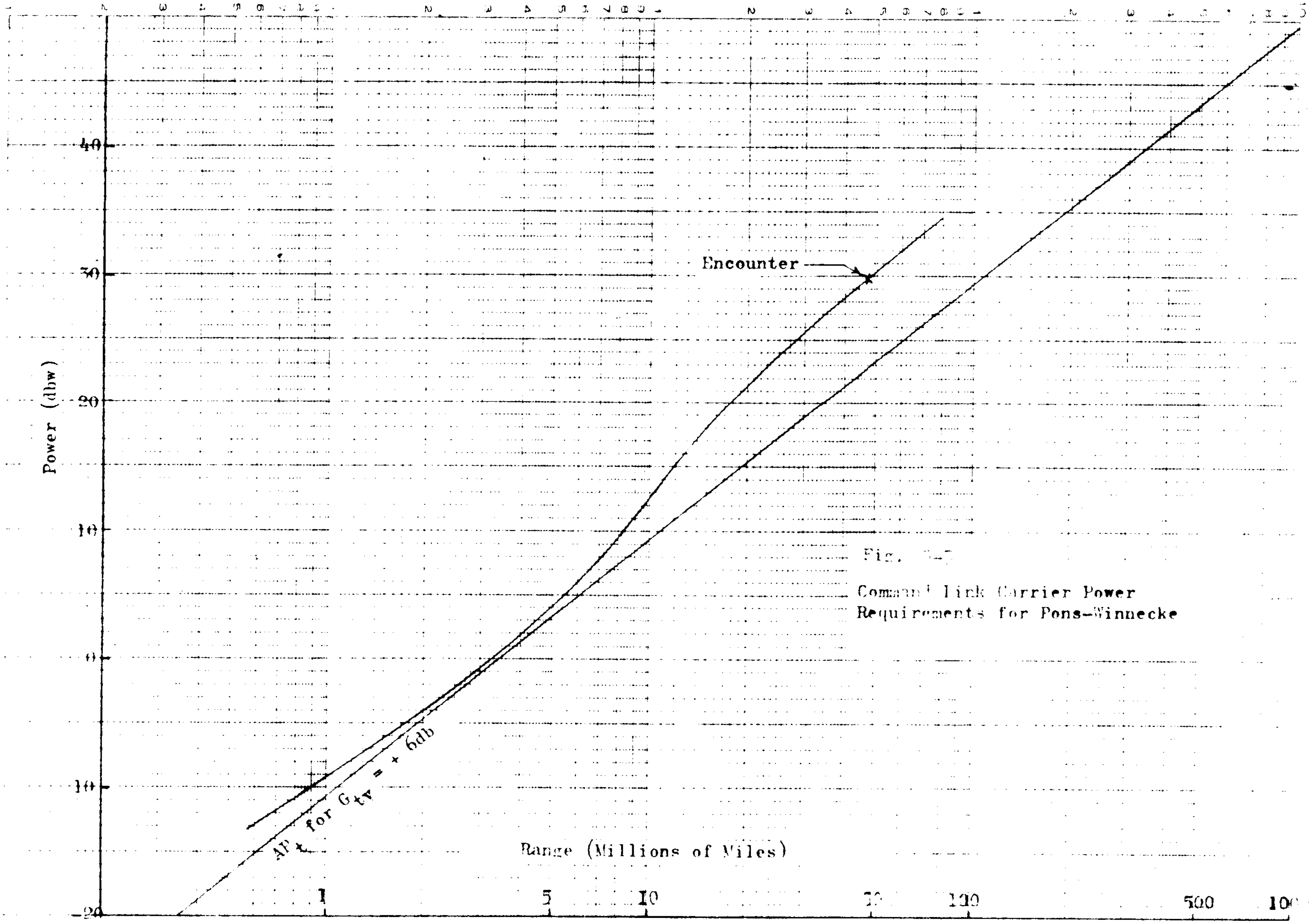


Fig.

Command Link Carrier Power Requirements for Pons-Winnecke

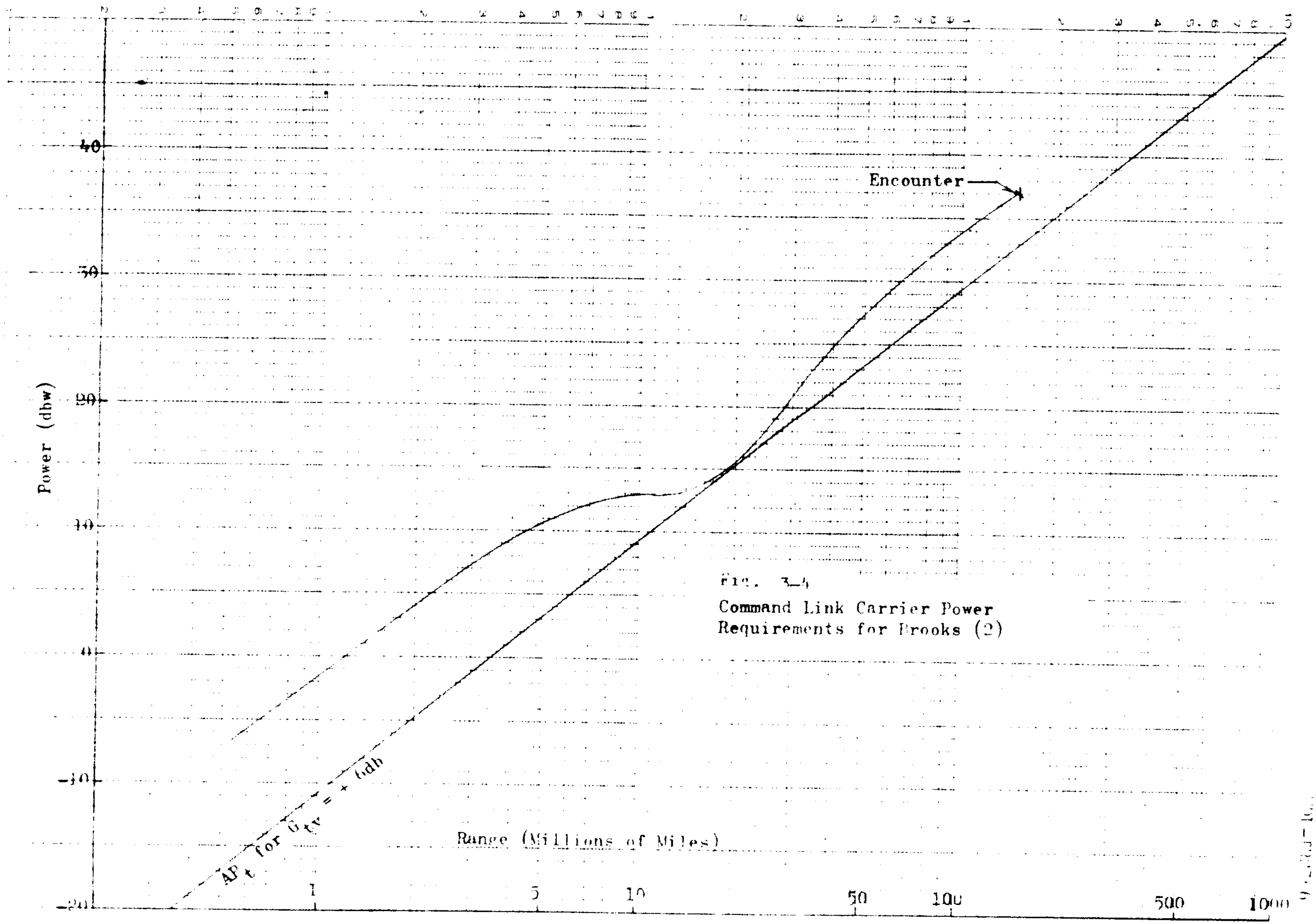
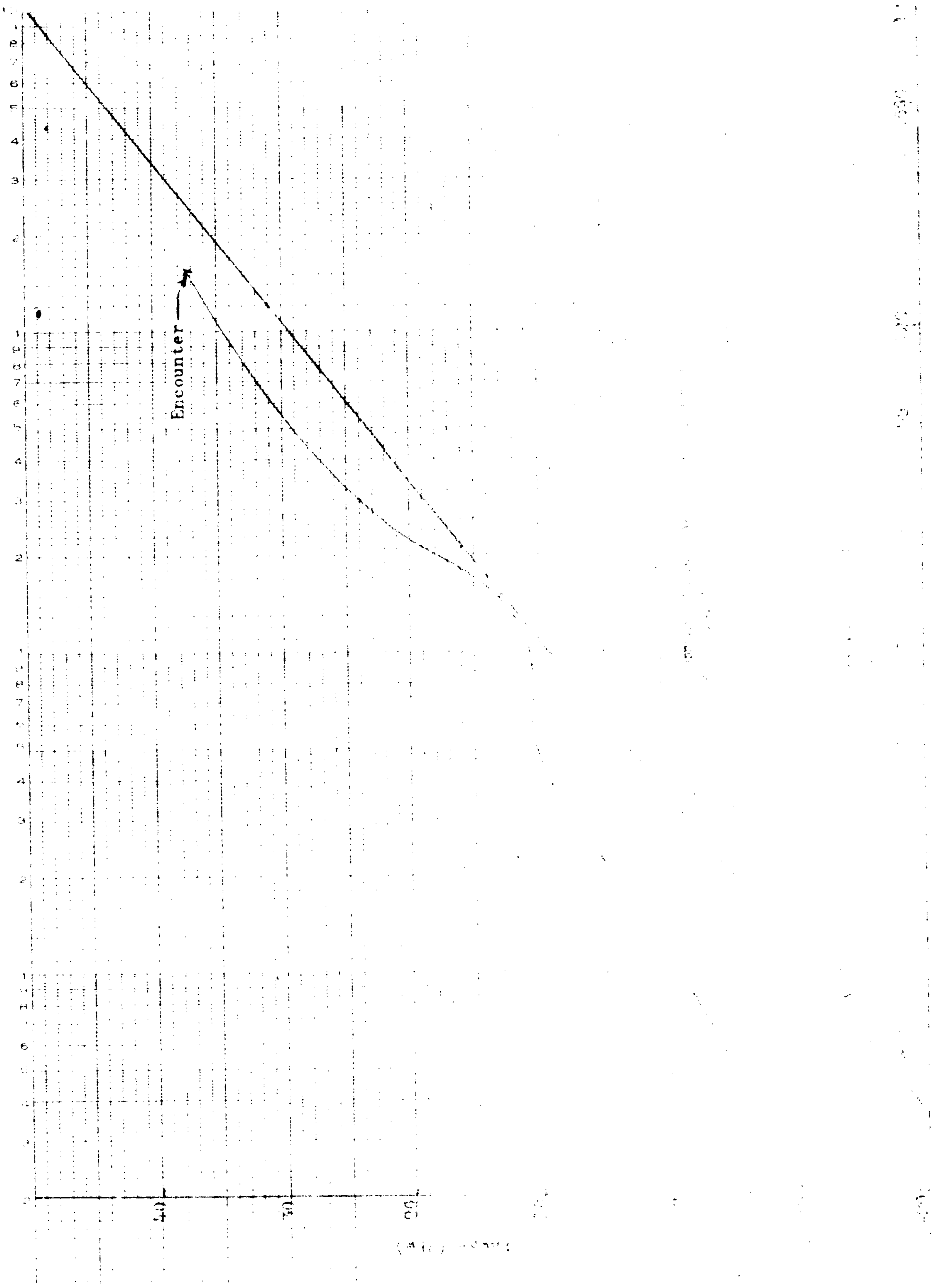


Fig. 3-4
Command Link Carrier Power Requirements for Brooks (2)


Encounter
40
30

All command systems are capable of good operation with at least several db margin at the extreme range and the 50 dbw capability is not required as it is for the Mariner-C. If for any reason the recommended pre-amplifier is not used, the ground transmitter power requirements will exceed 40 dbw in most cases. Should the 50 dbw capability be a requirement, the mission will depend on Goldstone, assuming that the 100 kw transmitter will not be installed elsewhere.

TABLE 3-1 COMMAND CAPABILITY AT ENCOUNTER

Link Power	Pons-Winnecke	Kopff	Brooks (2)	Tempel (2)
Intercept	30 dbw	37.5	37	24.2
Intercept +30 days	32.5 dbw	38	38	32.[illegible]

SECTION 4
TELEMETRY SUBSYSTEM

4.1 SUBSYSTEM REQUIREMENTS

The telemetry system utilizes PN-PSK/PM, as was recommended for the command link. In this case a complete unit cannot be recommended since the system depends on the specific experiments to be flown and their relative sample rates. The building blocks, however, can be those used on the Mariner-C spacecraft interconnected in a slightly different manner to accommodate the requirements peculiar to a comet probe.

4.1.1 Power Requirements

Assuming Mariner-C modulation techniques, a determination has been made of the system power requirements and transmitted data rate. In doing so the analysis presented in Appendix A has been used as a starting point; then the antenna gain variation with time was added. The positioning of the antennas and the calculation of the gain variation is discussed in Section 5. Figures 4-1, 4-2, 4-3 and 4-4 illustrate the carrier power requirements for the four most promising missions. The assumptions made in these calculations are use of the DSIF 85-foot dish, use of the Mariner-C high-gain antenna, use of the maser preamplifier at the receiving station, a 12-cps loop noise bandwidth with a required 6-db S/N ratio, and a 2-db link margin. Table 4-1 below tabulutes the power requirements and data capability of the telemetry link at and 30 days after intercept. For the data rate calculations the additional assumption is made of a constant 7-dbw modulation power being transmitted.

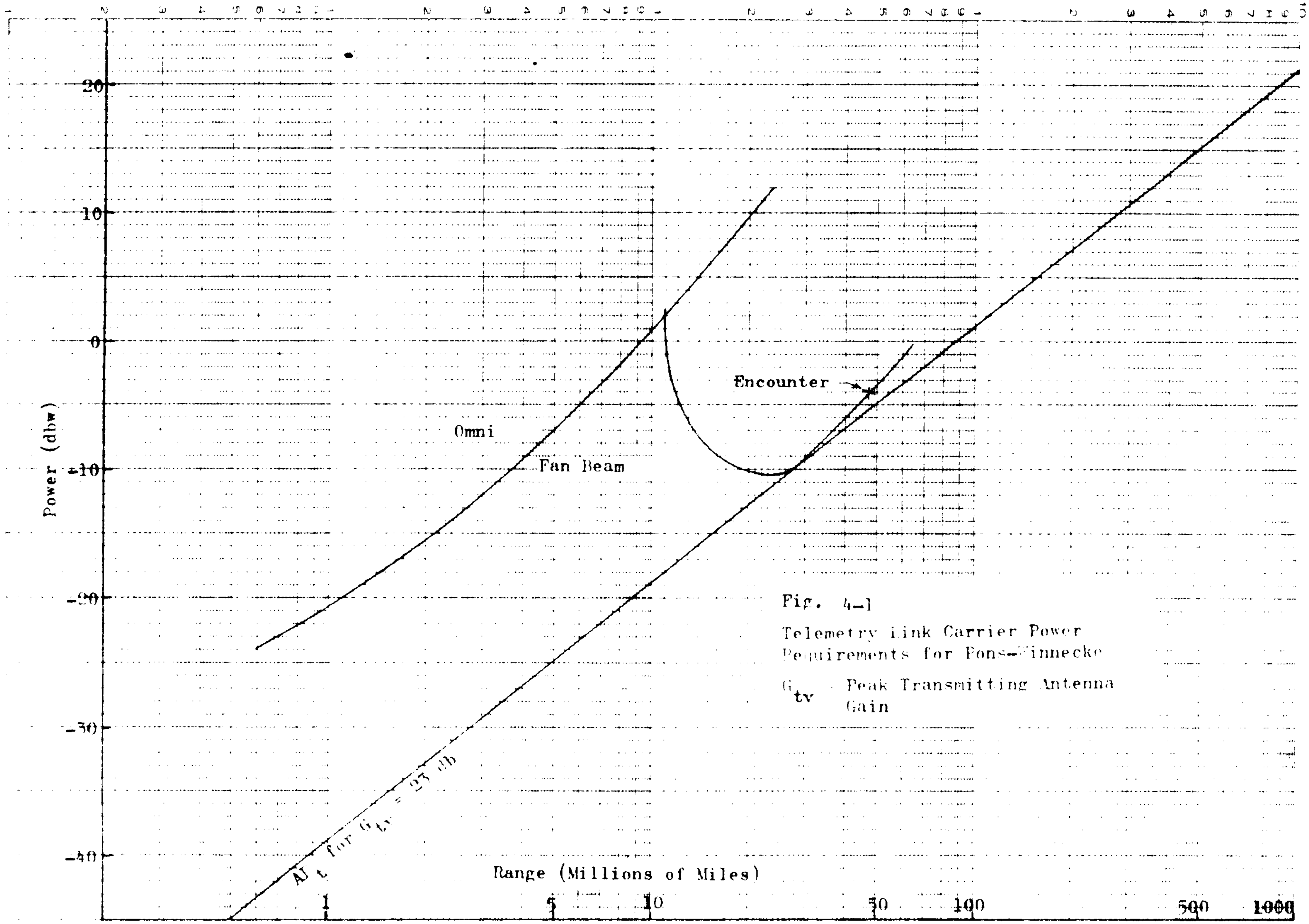
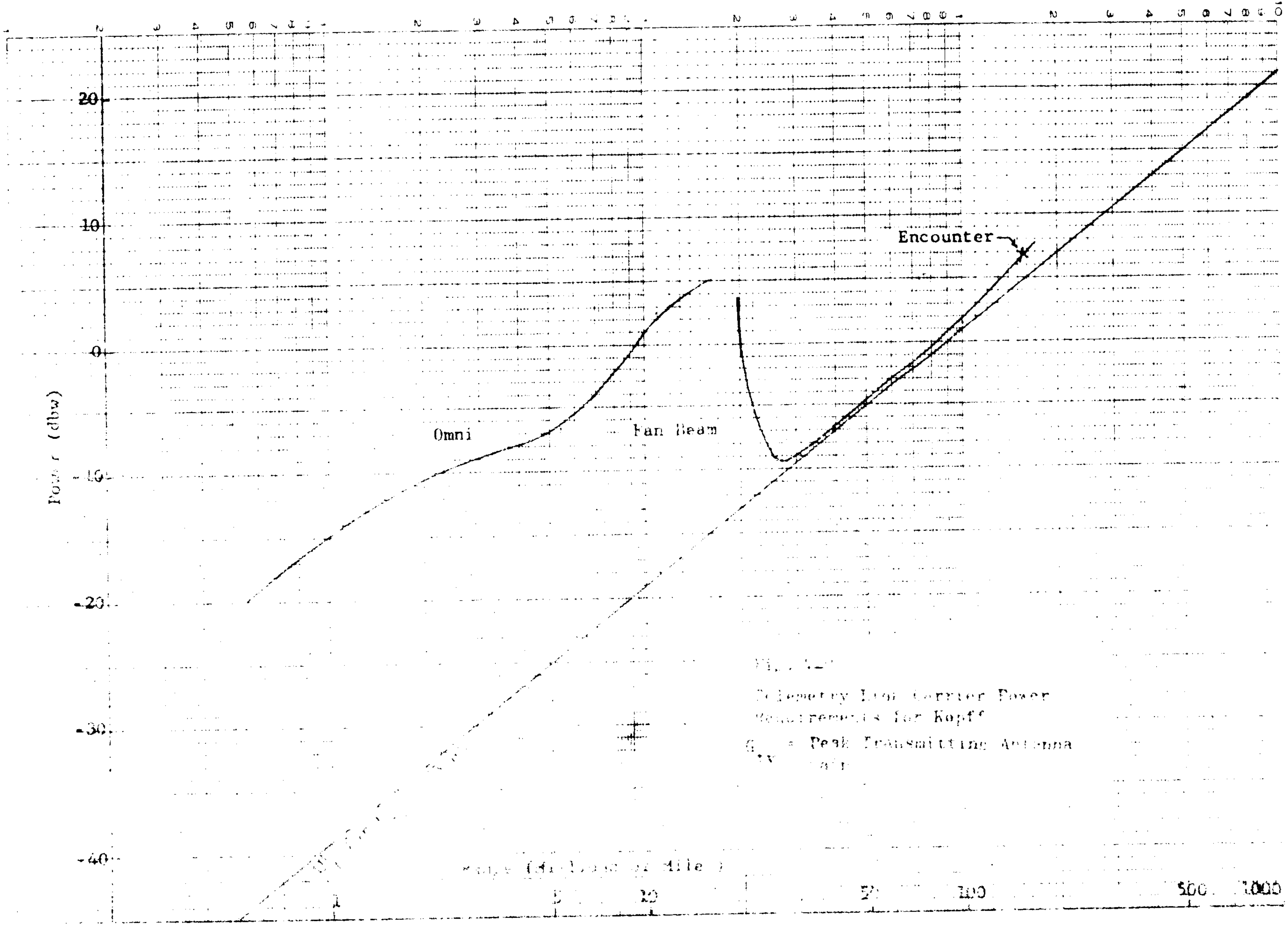
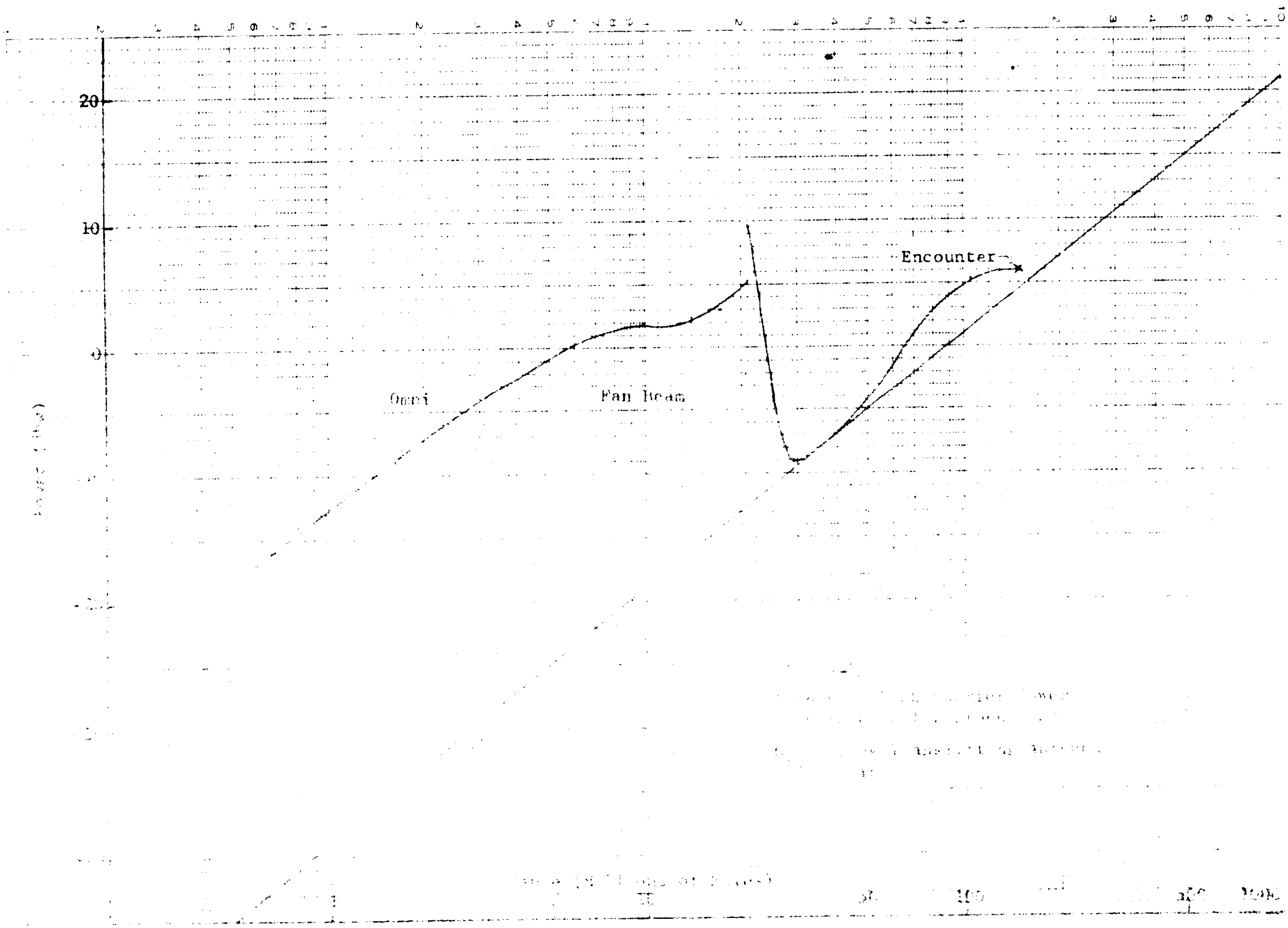


Fig. 4-1

Telemetry Link Carrier Power Requirements for Pons-Winnecke

G_{tv} Peak Transmitting Antenna Gain


Encounter
Omni
Fan Beam
Power (dbw)
20
10
0
-10
-20
-30
-40
1
5
10
50
100
500
1000


20
10
0
Omni
Fan Beam
Encounter

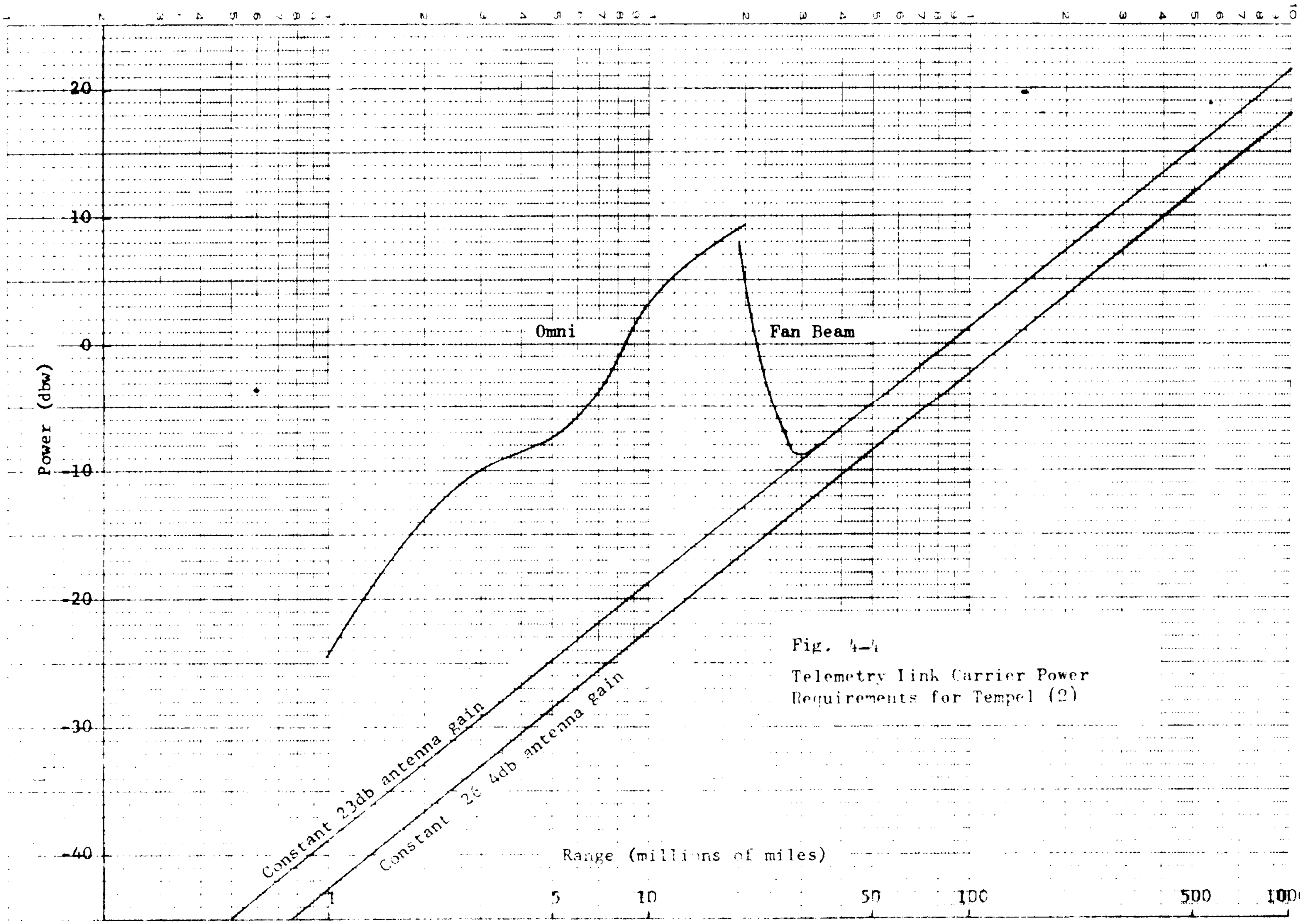


Fig. 4-4
Telemetry Link Carrier Power Requirements for Tempel (2)

TABLE 4-1 Telemetry Power Requirements and Data Rate Capability at Encounter

Comet Mission	T/M at Intercept		T/M at Intercept + 30 days		Comments
	AP_t (dbw)	R_b*	AP_t (dbw)	R_b*	
Pons-[illegible] ([illegible])	-4	19 db / [illegible]	-[illegible]	15 db / [illegible]	10 w transmitter [illegible] excel-lent [illegible]
Kopff (1970)	6.5	8.4 db / 7 bps	7.2	7.0 db / 5 bps	20 w transmitter required to pro-vide operation comparable to Mariner C
Brooks (2) (1973)	+6	9 db / 8 bps	+6	9 db / 8 bps	10 w transmitter provides Mariner-C capability
Tempel (2) (1967)	-7.5	27.5 db / 560 bps	-3	23 db / 200 bps	10 w transmitter provides an excel-lent system

*R_b based on 7 dbw modulation power

4.1.2 Data Requirements

An estimate has been made of required engineering telemetry data and is tabulated in Table 4-2. A similar tabulation of scientific telemetry data during cruise and intercept is given in Table 4-3. From these data requirements, the storage capacity needed during intercept and the time needed for playback after intercept can be determined as follows. The relative speed between the spacecraft and comet at intercept is of the order of 10 km/sec. Beginning intercept at 10^6 km away from the point of closest approach defines the intercept period as being 2×10^5 seconds long, or 53.3 hours. Table 4-3 shows that for science, except TV, about

Table 4-2 Engineering Telemetry Data

LOCATION	NO.	ACCURACY	RATE
Thermal Subsystem			
Heat Shield	4	5%, 6 bits	2/day
Antenna	4	5%, 6 bits	2/day
Insulation Surface*	8	5%, 6 bits	2/day
Thermal Control Surface*	10	5%, 6 bits	2/day
Internal Equipment*	5	5%, 6 bits	2/day
External Equipment*	5	5%, 6 bits	2/day
Isotope	4	5%, 6 bits	2/day
Active Temperature Control	8	5%, 6 bits	1/week
Scientific Instruments			
Voltages	10	5%, 6 bits	1/day
Communication Subsystem			
AGC Voltage	3	5%, 6 bits	1/30 s/s
Command Detector Lock Indicator	1	1 bit	1/30 s/s
Ranging Module Phase Error	1	5%, 6 bits	1/30 s/s
Transponder Loop Phase Error	1	5%, 6 bits	1/30 s/s
Command Loop Phase Error	1	5%, 6 bits	1/30 s/s
Ranging Module Lock Indicator	1	1 bit	1/30 s/s
Ranging Module AGC Indicator	1	1 bit	1/30 s/s

* During midcourse maneuvers the rate of these measurements is 1 sample per 5 minutes.

LOCATION	NO.	ACCURACY	RATE
Structures and Mechanisms			
Squibb Firings	11	event, 1 bit	1/30 s/s
Deployments	5	event, 1 bit	1/30 s/s
Antenna Hinge Angles	2	6 bits	1/30 s/s
Photovoltaic Power S/S			
Solar Panel Temperature			
Front	4	5%, 6 bits	2/day
Back	4	5%, 6 bits	2/day
Panel Voltage	4	5%, 6 bits	2/day
Panel Current	4	5%, 6 bits	2/day
Isotopic Power Subsystem			
Output (V, I)	8	5%, 6 bits	2/day
Temperatures	4	5%, 6 bits	2/day
Power Distribution			
Power Inverter Output	2	5%, 6 bits	2/day
Transformer Rectifier Outputs	12	5%, 6 bits	2/day
Battery Charger	2	5%, 6 bits	2/day
Battery Power Output	2	5%, 6 bits	2/day
Guidance & Control S/S			
Pressures	4	5%, 6 bits	2/day
Temperatures	2	5%, 6 bits	2/day
Events	4	1 bit	2/day
Vane Angles	2	5%, 6 bits	2/day

Table 4-3 Scientific Telemetry Data

Experiment	Intercept	Cruise
Magnetometer	8-1/3, 33-1/3	2.0
Dust Detector	5	0.2
Plasma Probe	45	0.8
Ionization Chamber	5	0.2
Planar Trap	45	0.2
Gieger-Mueller Tube	5	0.2
Bistatic Radar	1	0.1
Ion Mass Spectrometer	150	--
UV Photometer	1	--
UV Spectrometer	33-1/3	--
TV	10 pictures during a 28-hour period (1 picture = 1.28×10^6 bits)	--
Total Bit Rate Required:	298-2/3 Plus TV 323-2/3 Plus TV	3.7 bps

a 300-bps transmission rate is required of the telemetry subsystem. This represents 6×10^7 bits for the entire intercept period. If it is further assumed that 20 TV pictures (10 pictures with two color filters) are adequate for the mission, a total of 6.3×10^7 bits of data are accumulated during each encounter. Finally, it is assumed that this data is to be played back twice to the DSIF. This establishes a 6.3×10^7 bit requirements on the intercept data storage and 1.3×10^8 bits to be played back during the post-intercept period. For a storage device of this capacity the only reasonable device is a tape recorder of the type being developed for Mariner '69 - '71.

4.2 TELEMETRY CAPABILITY

Figures 4-5, 4-6, 4-7, and 4-8 illustrate data rate capbility versus geocentric range based on a 10-watt transmitter. Using the information found in Figures 4-5, 4-6, 4-7 and 4-8 plots have been made of the total data transmission capability versus days of transmission time for missions to Pons-Winnecke, Kopff and Brooks (2) and Tempel (2). It is assumed that the bit rate is constant and equal to the bit rate capability of the final day of transmission. The curves plotted are based on the data rates at 30 days after intercept and are presented in Figures 4-9, 4-10 and 4-11. Table 4-4 summarizes this information. This information can be interpreted in three different ways:

1. The time required to transmit a given number of bits with a given system.
2. The total number of bits that can be transmitted in a given time with a given system.
3. The system required to transmit a given number of bits in a given time.

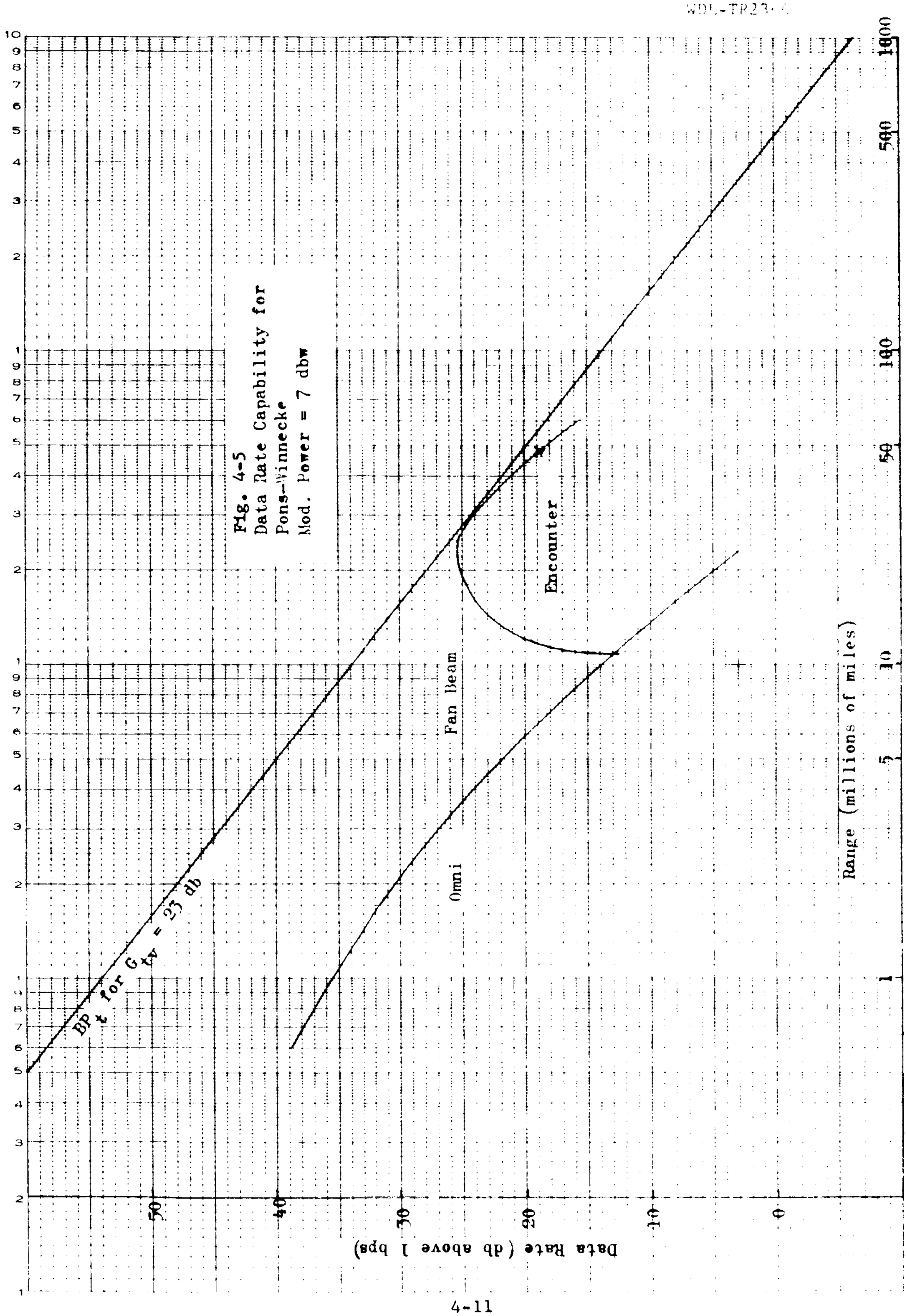


Fig. 4-5
Data Rate Capability for
Pons-Winnecke
Mod. Power = 7 dbw

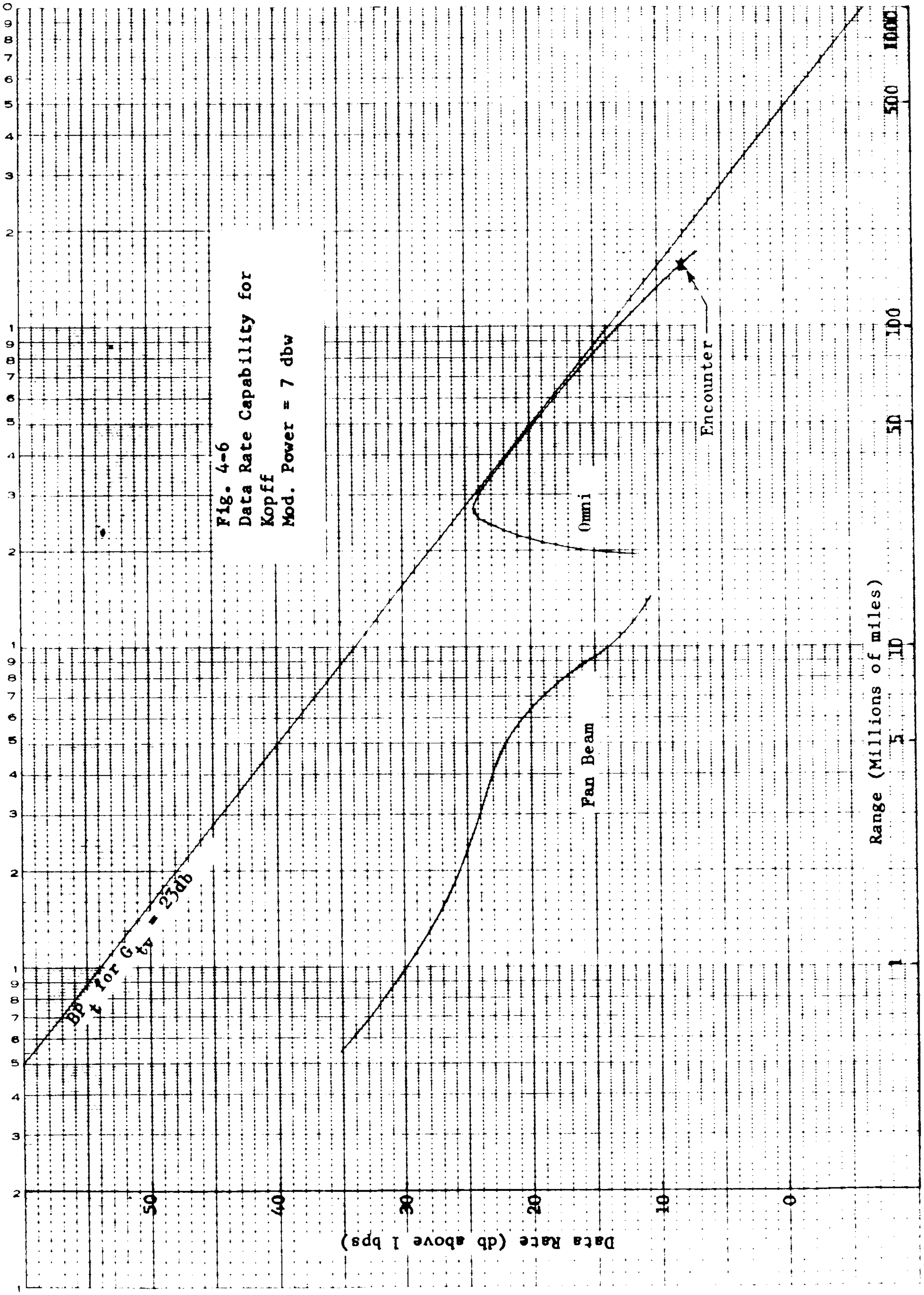


Fig. 4-6
Data Rate Capability for
Kopff
Mod. Power = 7 dbw

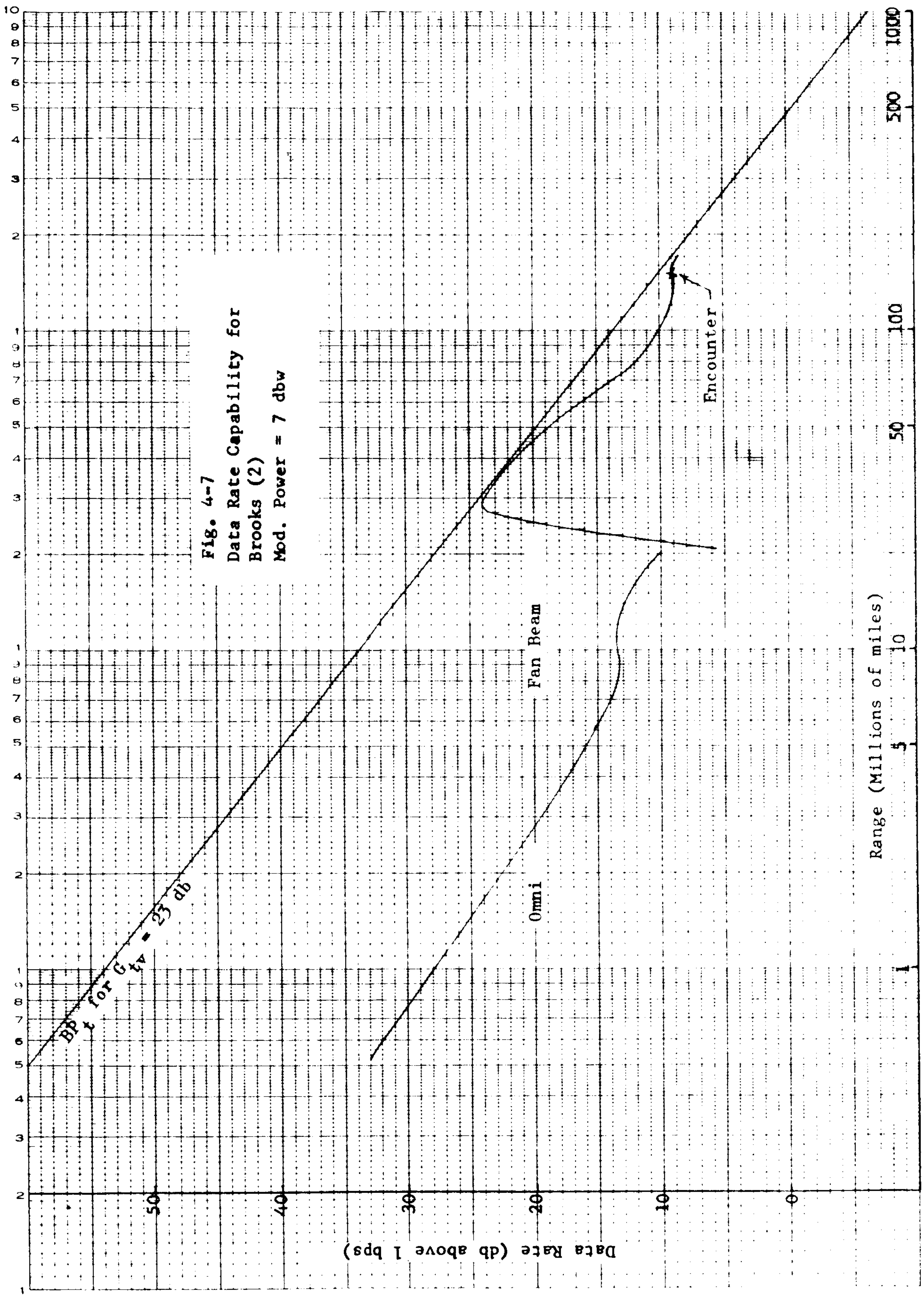


Fig. 4-7
Data Rate Capability for Brooks (2)
Mod. Power = 7 dbw

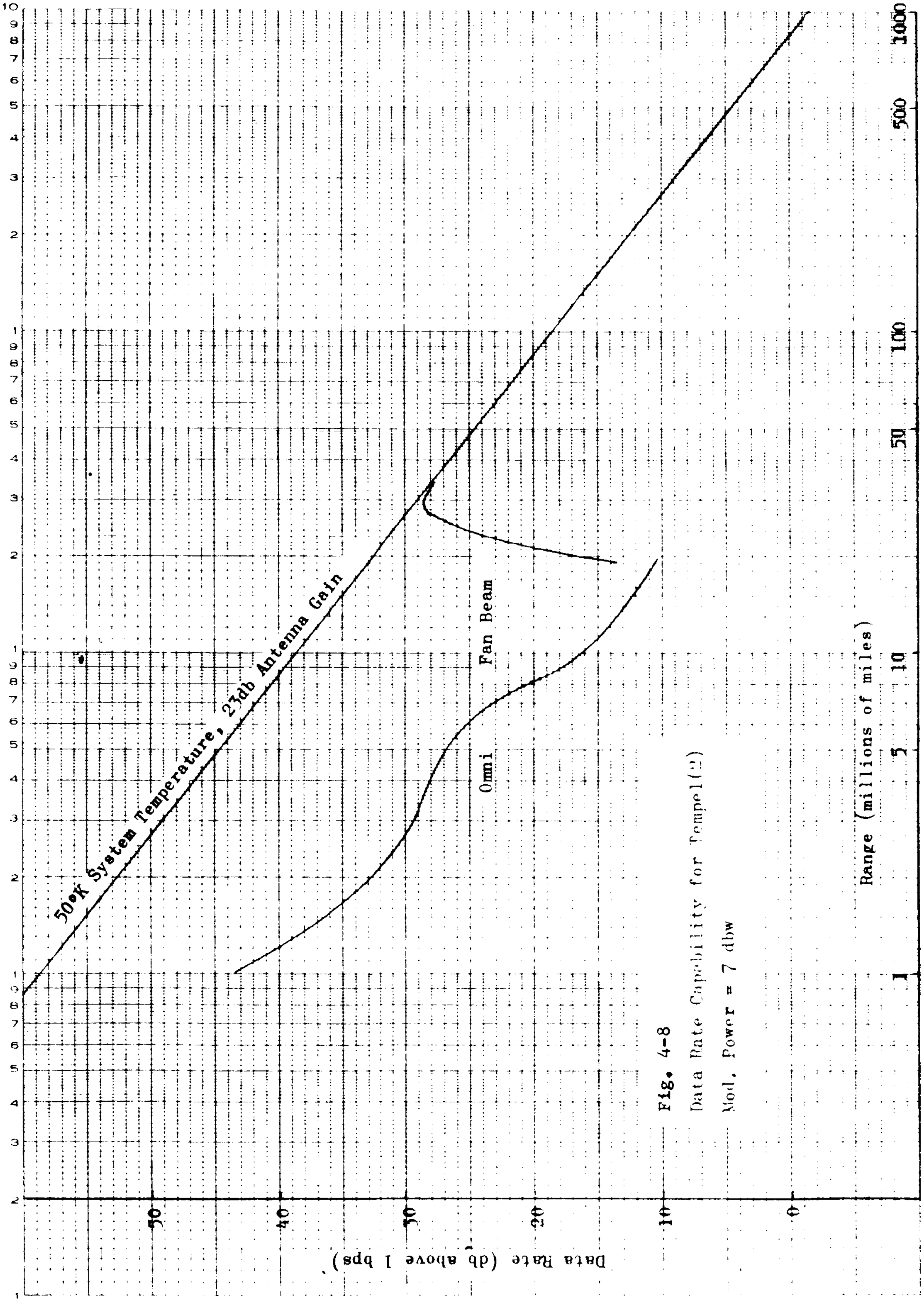
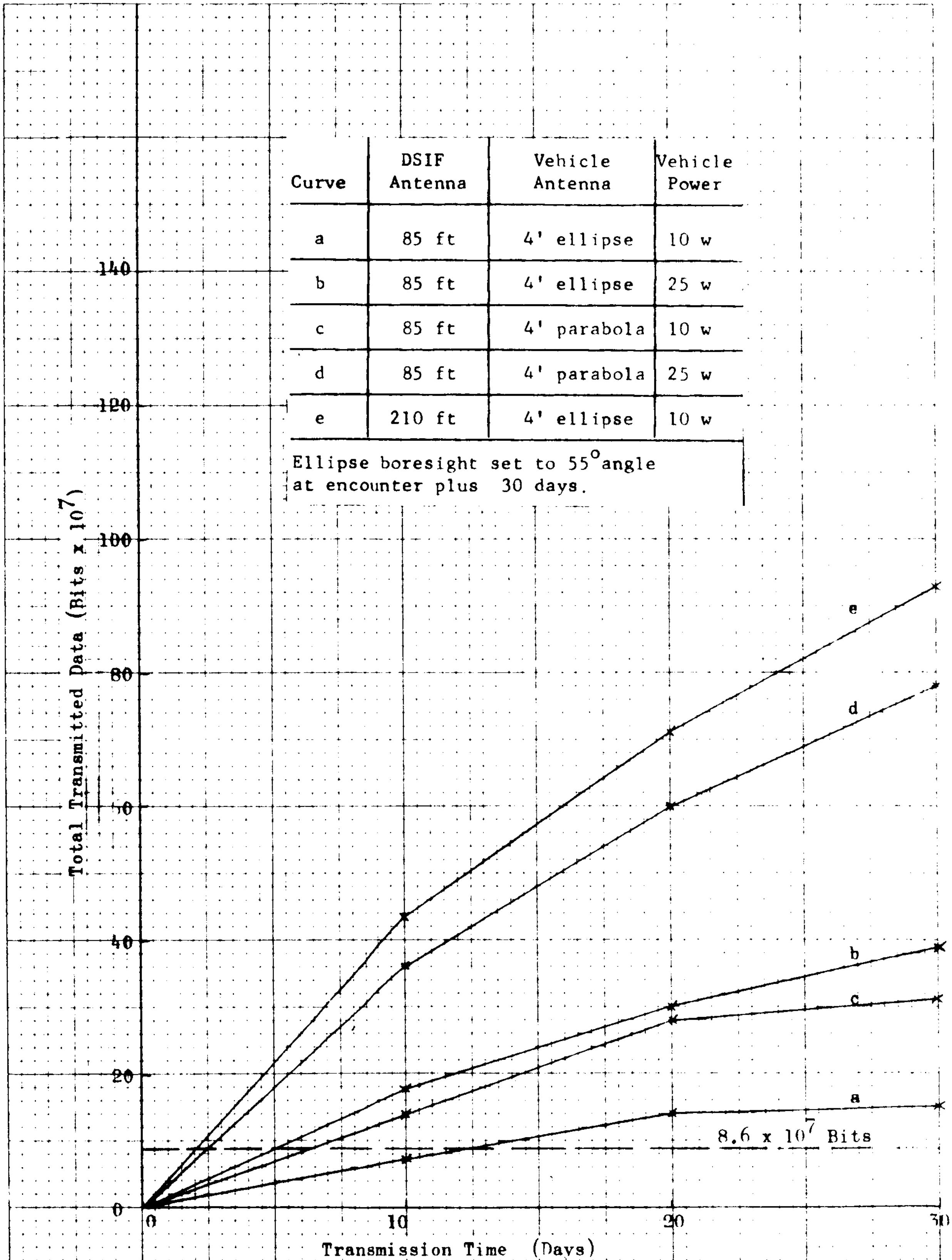


Fig. 4-8

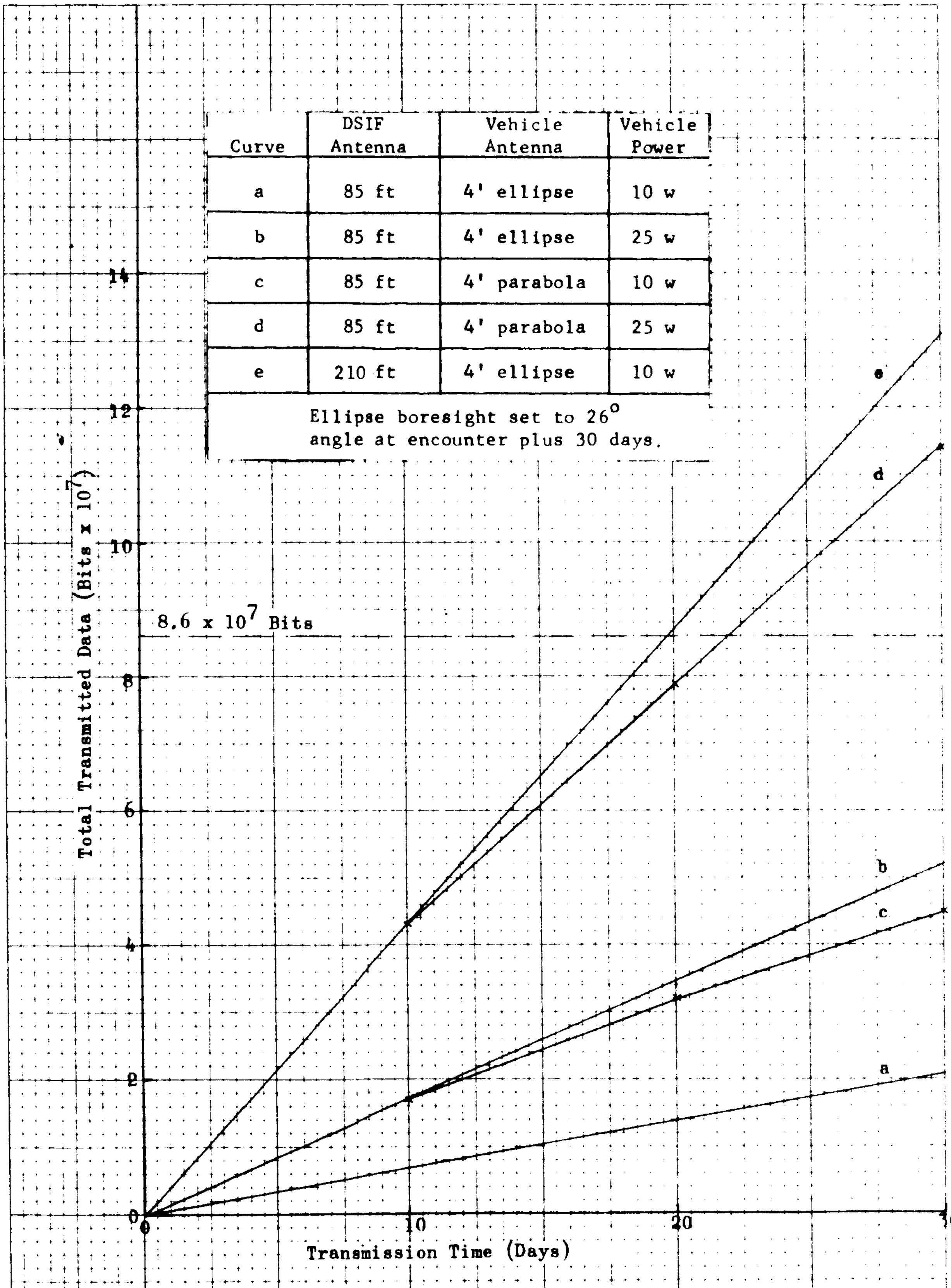
Data Rate Capability for Tempel(2)

Mod. Power = 7 dbw



Curve	DSIF Antenna	Vehicle Antenna	Vehicle Power
a	85 ft	4' ellipse	10 w
b	85 ft	4' ellipse	25 w
c	85 ft	4' parabola	10 w
d	85 ft	4' parabola	25 w
e	210 ft	4' ellipse	10 w

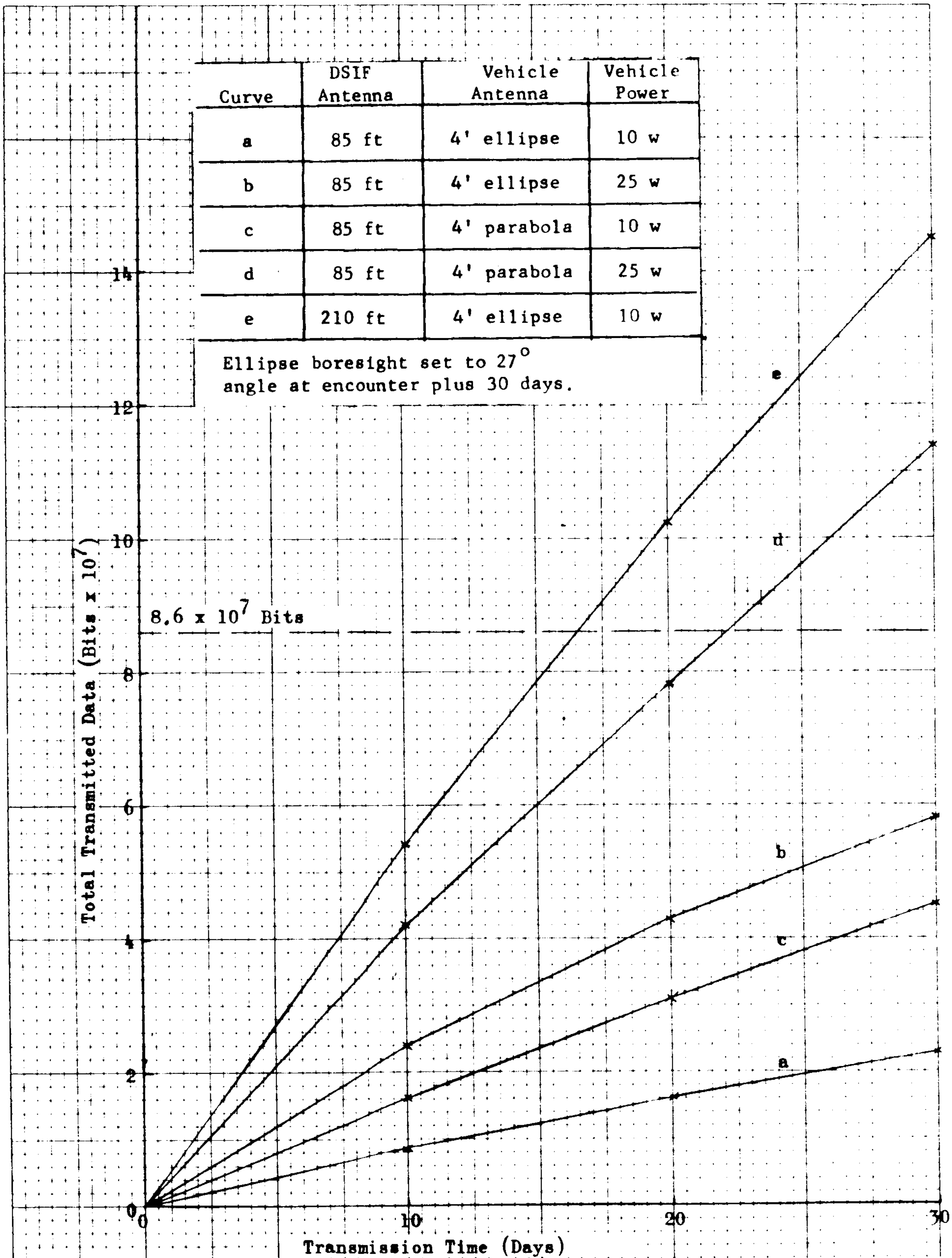
Fig. 4-9 Total Encounter Data Recoverable for Pons-Winnecke



Curve	DSIF Antenna	Vehicle Antenna	Vehicle Power
a	85 ft	4' ellipse	10 w
b	85 ft	4' ellipse	25 w
c	85 ft	4' parabola	10 w
d	85 ft	4' parabola	25 w
e	210 ft	4' ellipse	10 w

Ellipse boresight set to 26° angle at encounter plus 30 days.

Fig. 4-10 Total Encounter Data Recoverable for Brooks (2)



Curve	DSIF Antenna	Vehicle Antenna	Vehicle Power
a	85 ft	4' ellipse	10 w
b	85 ft	4' ellipse	25 w
c	85 ft	4' parabola	10 w
d	85 ft	4' parabola	25 w
e	210 ft	4' ellipse	10 w

Fig. 4-11 Total Encounter Data Recoverable for Kopff

Table 4-4 Comparison of Intercept Data Transmission Capabilities

Mission	System	Transmission Time in Days for 8.6×10^7 bits (days)	Transmitted bits $\times 10^7$ for 30 days transmission
Pons-Winnecke Boresight at 55^o Cone Angle	a	14	15.5
	b	5	39
	c	6	31
	d	2.5	78
	e	2	93
Kopff Boresight at 27^o Cone Angle	a	-	2.3
	b	-	5.8
	c	-	4.5
	d	22.5	11.4
	e	16.5	14.5
Brooks (2) Boresight at 26^o Cone Angle	a	-	2.1
	b	-	5.2
	c	-	4.5
	d	22	11.4
	e	19.7	13.1

System	DSIF Antenna	S/C Antenna	S/C Power	Antenna Pointing
a	85 foot	4' ellipse	10w	2 antenna positions required
b	85 foot	4' ellipse	25w	2 antenna positions required
c	85 foot	4' parabola	10w	continuous positioning required
d	85 foot	4' parabola	25 w	continuous positioning required
e	210 foot	4' ellipse	10w	2 positions required

The maximum transmission time considered is 30 days. This is an increase in required spacecraft lifetime beyond intercept of 20% for Pons-Winnecke, 14% for Brooks (2), and 10% for Kopff. Further increases in transmission times will produce smaller increases in total transmission capability for larger increases in the probability of failure.

Curves a, b, and c on these plots and on the table represent the simplest systems and have the minimum requirements in terms of antenna pointing requirements. However, System e requires the use of the 210-foot dish at the DSIF for the reception of data during intercept. Based on the latest DSIF development schedule [JPL, 1964], the only 210-foot dish presently authorized to be built is the one at Goldstone. Antennas at Canberra and Madrid have been proposed. If only the dish at Goldstone is available at the time of the mission, the recoverable data with System e must be divided by three. Systems c and d provide improved system operation as compared to Systems a and b respectively but are less reliable due to the additional antenna pointing requirements of the pencil-beam parabola.

4.3 POWER AMPLIFIERS

The choice of power amplifier today is a TWT. This selection is based on proven reliability and proven performance, e.g., efficiency, gain and ability to survive in a space environment. The characteristics of TWT's are well known and it has been demonstrated that tubes can be built which will operate for more than one year. The maximum mission lifetime, including post-intercept playback, is 330 days for Brooks (2). The characteristics desired in the tube are listed below for two power levels:

R. F. Power Output	10 watts	25 watts
Frequency	2300 Mc	2300 Mc
Gain	20 db min.	20 db min.
Efficiency	25% min.	[illegible]
Operational Life	10 months continuous	[illegible] continuous
Mean Time to Failure (MTTF)	30,000 hr.	[illegible]
Operating Temperature	0°C to 50°C	[illegible]
Weight	7 lbs. max.	10 [illegible] max.

TWT characteristics and failure modes have been analyzed thoroughly beginning with the well-known Bell Labs work. Based on these and continued studies, highly reliable tubes with MTTF of 30,000 hours are being produced. The limiting factor in the life of the tube now seems to be the cathode. Watkins-Johnson has been working on this problem and now claims a tube with a predicted MTTF of 50,000 hours.

Table 4-5 is a list of the more promising tubes available in the [illegible] and 20-watt range. Three types of tubes are listed: TWT, Amp[illegible] Klystron. There are, of course, magnetrons and [illegible]; [illegible] the state-of-the-art of these devices in reliability and efficiency [illegible] inadequate. It is realized that a Siemans triode with [illegible] being flown on the Mariner-C; however, the MTTF of the device is [illegible] 6000 hours which is quite poor compared to what can be obtained with TWT.

The Litton Industries Klystron appears to be adequate in all its characteristics; however, it is inferior to both the Amplitrons and the TWT's listed. At present, it is a development item for backup for the Apollo TWT. Testing and evaluation are in process. The unit should be kept in mind for future application. The Raytheon Amplitrons must at this time

Table 4-5 POWER AMPLIFIER CHARACTERISTICS

TUBE	POWER OUT (w)	GAIN (db)	EFF. (%)	EXPECTED LIFE (hr)	TUBE WEIGHT	REMARKS
Hughes, 349H TWT	10	30	30	30,000	15 oz	Designed for Surveyor
Hughes, 394H TWT	5	20	30	90,000	20 oz	Designed for Apollo
	20	26	35	25,000	20 oz	Power continuously variable 5-20 w
Watkins-Johnson 274, TWT	20 (25 w max)	30	40	50,000	9 oz	Development Contract for Goddard; 3.1 lbs with power supply
Watkins-Johnson 227-5, TWT	12	33	25	30,000	32 oz	Flight Qualified
Raytheon, Amplitron QKS 997A	20	20	35	30,000	7 lbs	All 3 Models Include Power Supply
Raytheon Amplitron QKS 1300	20	20	35	30,000	7 lbs	Designed for Lunar Excursion Module
Raytheon Amplitron QKS 1200	10	20	35	30,000	5.5 lbs	Designed for Nimbus at 1700 Mc
Litton Industries L3910, Klystron	5	20	22	25,000	40 oz	Developed as Backup to Apollo TWT with 2 Power Modes
	25	20	29	25,000	40 oz	

be considered in the same light, i.e., not for immediate use. Although they compare favorably in every respect with the TWT's, they have yet to be demonstrated in flight. This will take place in the near future since the QKS 1300 will be used on the Apollo Lunar Excursion Module and the QKS 1200 on the Nimbus satellite. The TWT's, on the other hand, are proven devices and although the particular unit may not have flown the technology is well established. The Hughes 294H, for example, is based on the same principles that led to the Syncom TWT which has operated in orbit for over two years. The WJ-274 is a new tube but developed on proven techniques as demonstrated by Watkins-Johnson's previous units, e.g., the WJ-227-5.

Based on the above argument, the tubes selected at this time are the Hughes 249H for the 10-watt unit and the WJ-274 for the 25-watt unit. If the WJ-274 is not available or encounters difficulties in its qualification tests, the Hughes 394H is recommended.

There is one advantage to using Amplitrons. Figure 4-12 below shows a pair of Amplitrons connected in series. The characteristics of Amplitrons are such that, with the unit turned off an input signal appears at the output attenuated by a few tenths of a db. Assuming a 10-watt output for each unit in Figure 4-12 either can be turned on to provide the 10-watt output. This provides an overall simpler and more reliable arrangement for switching redundant power amplifiers as compared to what must be used with TWT's. In addition, the insertion of an isolator between the two Amplitrons permits simultaneous operation thereby providing twice the power output. Without the isolator, this is not possible because reflections in the system tend to cause oscillations.

45

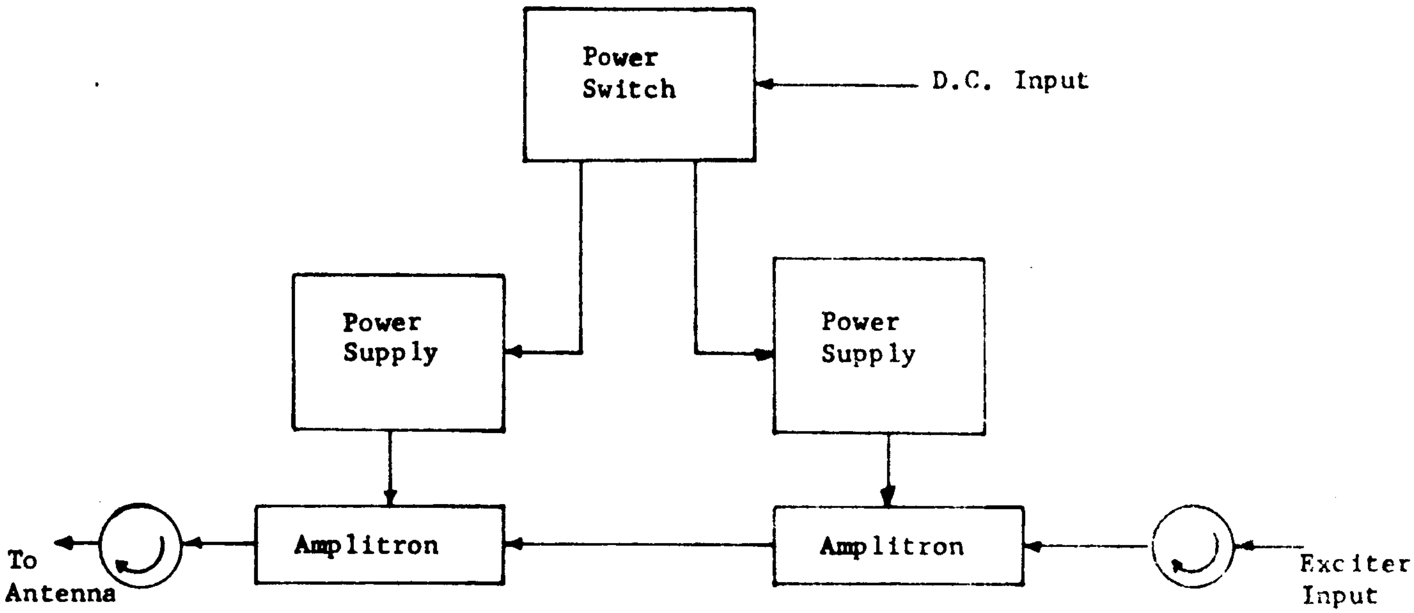
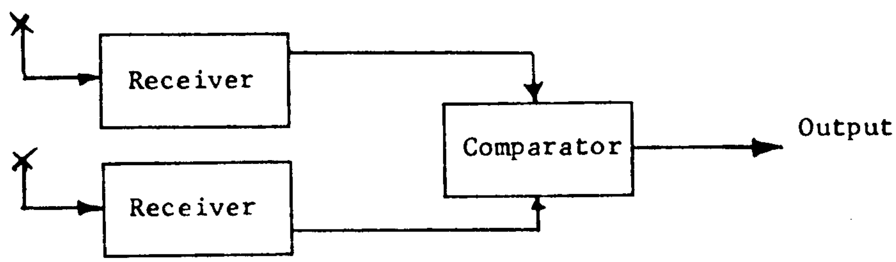


Fig. 4-12 Amplitron Power Amplifier

SECTION 5
SPACECRAFT ANTENNAS

5.1 LOW-GAIN ANTENNA

The requirements of the omni antenna can be defined by five parameters; the cone angle, the clock angle, the gain required, the polarization and whether it is to be used for receiving and/or transmitting. Circular polarization is recommended for both transmitting and receiving. There is no advantage to using linear polarization. Omnidirectional coverage is desired in order to be able to address the spacecraft regardless of its orientation. In order to realize omni coverage, duplicate receiving systems as indicated below can be used:



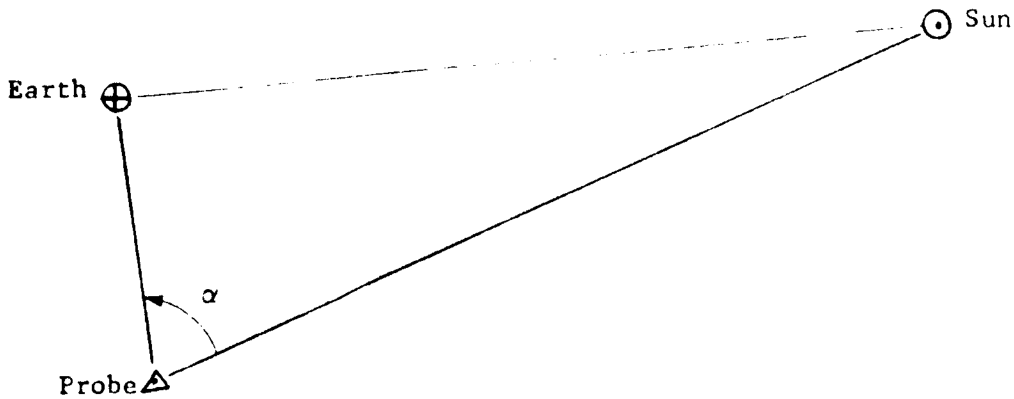
Two antennas, each with hemispherical coverage, are used back to back. In order to switch from one antenna to another, a comparator is used to compare the relative signal strengths seen by the two receivers and select the better of the two. This system is less reliable and at least twice as expensive in terms of weight, power, and size. Its advantage is an increase in antenna gain and complete omnidirectional coverage. However, it will be shown that the coverage provided by the Mariner-C antenna is adequate for a comet probe. It will also be shown that the only time the low-gain region of the antenna is aimed near the Earth is during the launch portion of the flight. During launch the low space loss results in a high link margin.

The cone angle is defined as the angle between the earth-probe and probe-sun lines as shown in Figure 5-1a. If the probe-sun line is held fixed and the probe-earth line is rotated about it at the fixed angle, a cone is generated. Let a plane be passed through the cone perpendicular to the probe-sun line. The intersection of the cone and the plane is a circle as shown in Figure 5-1b. Now label celestial north as 0° and let the angle be measured clockwise. This is the clock angle. The clock angle at any particular time is defined by the intersection of the earth-probe line with the circle.

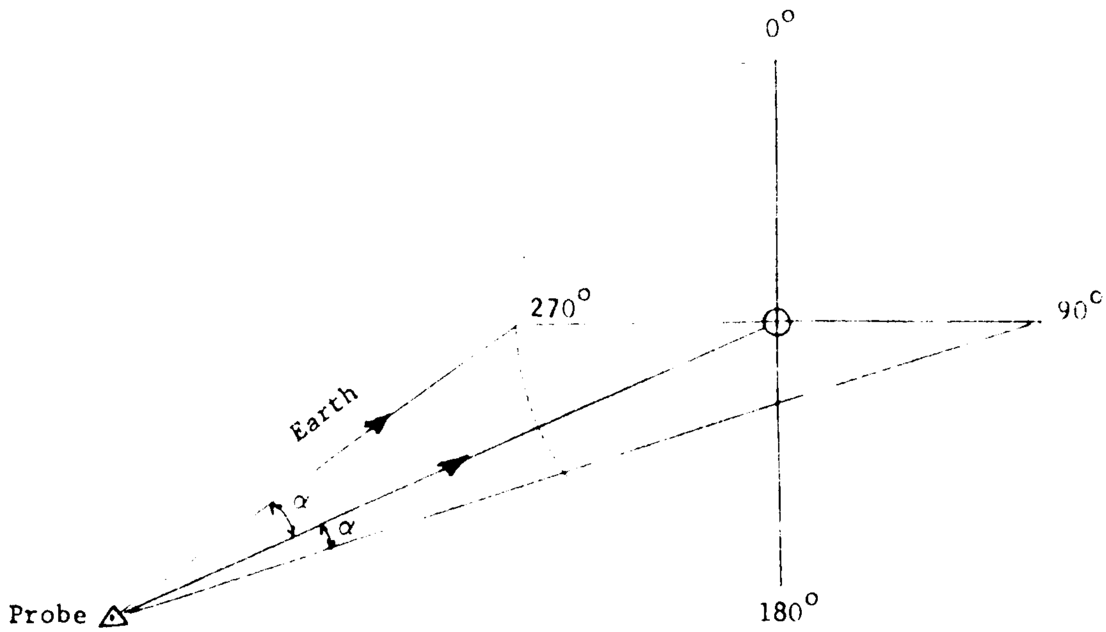
Figures 5-2, 5-3, and 5-4 are the cone angle variations for Pons-Winnecke Brooks (2) and Kopff. Figures 5-5, 5-6, and 5-7 show the clock angle for the corresponding comets. The coverage required varies from one comet to another, but is always satisfied by the Mariner-C omni charact-ertstics. In order to show the effects on the power requirements and data rate capabilities, the angle characteristic variations must be related to the range of the probe at any time. Figures 5-8, 5-9 and 5-10 indicate range versus flight time and can be used with the angle information to define the angles at any range.

5.1.1 Omni Antenna Design

The omni antenna is a body-fixed structure. If it is aimed at the sun, the clock angle plots in Figures 5-5, 5-6, and 5-7 indicate that in order to satisfy all comet requirements, at least 110° coverage away from the sun line is required. Although the Mariner-C antenna satisfies both of these requirements, it is too long to fit within the Centaur shroud. This means that it must be shortened. This will not effect its operation in any way; and since it is not intended that the antenna be used as a mast on which to mount instruments, nothing is lost. The present low-gain design consists of a waveguide-fed parasitic array, as shown in Figure 5-11a.



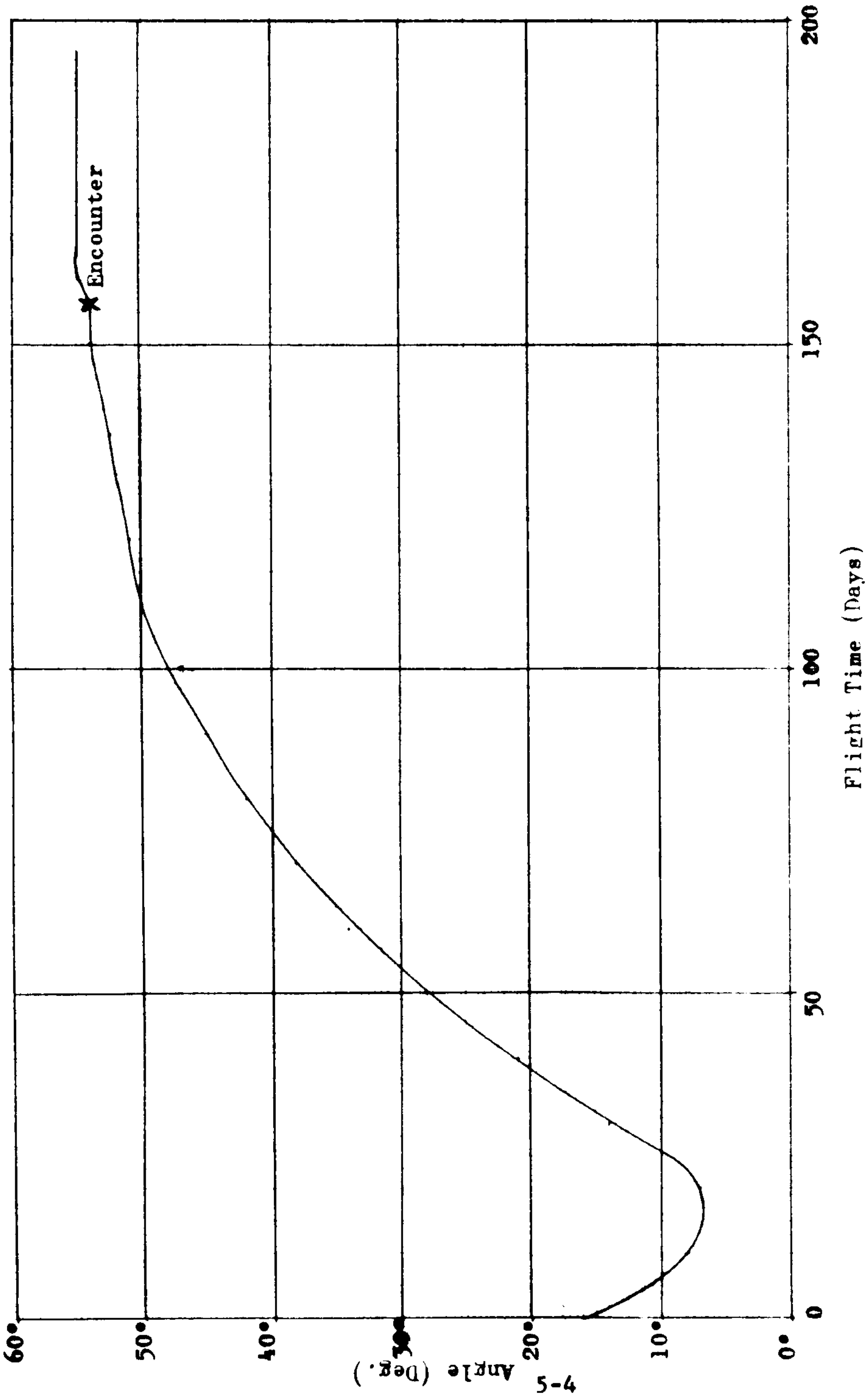
(a) Cone Angle



(b) Clock Angle

FIG. 5-1 Antenna Angles

Fig. 5-2 Earth-Probe-Sun Angle for Pons-Winnecke



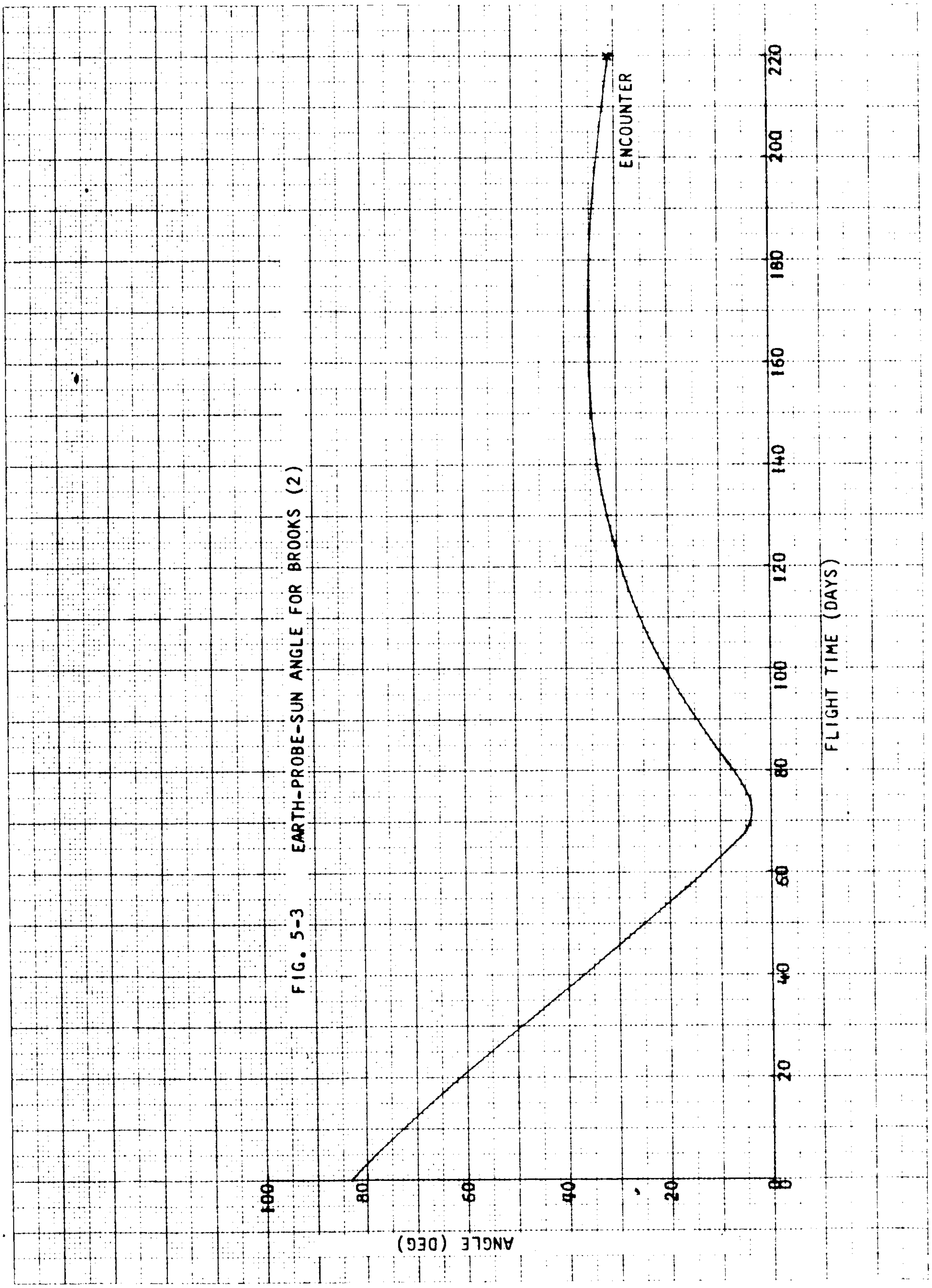
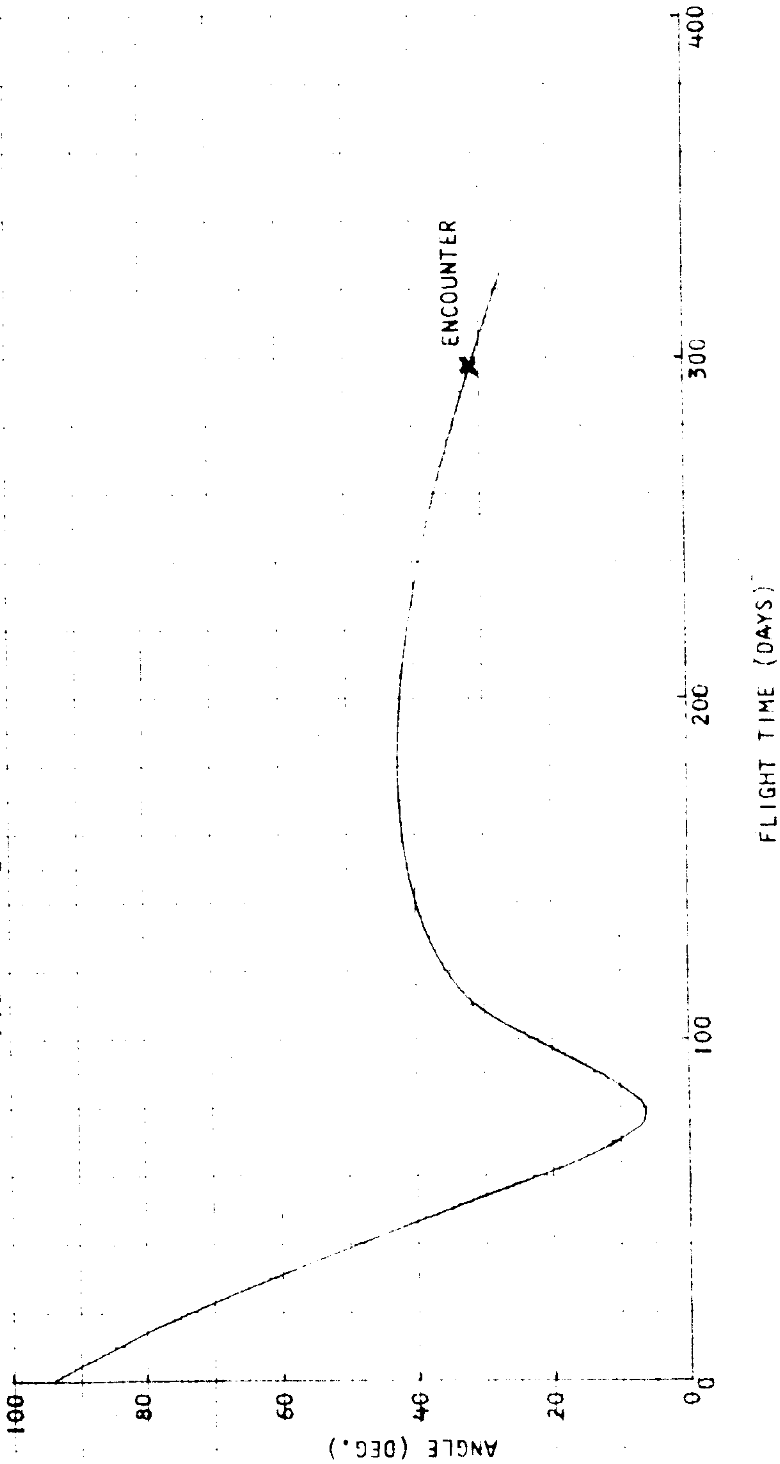


FIG. 5-3 EARTH-PROBE-SUN ANGLE FOR BROOKS (2)

FIG 5-4 EARTH-PROBE-SUN ANGLE FOR KOPFF



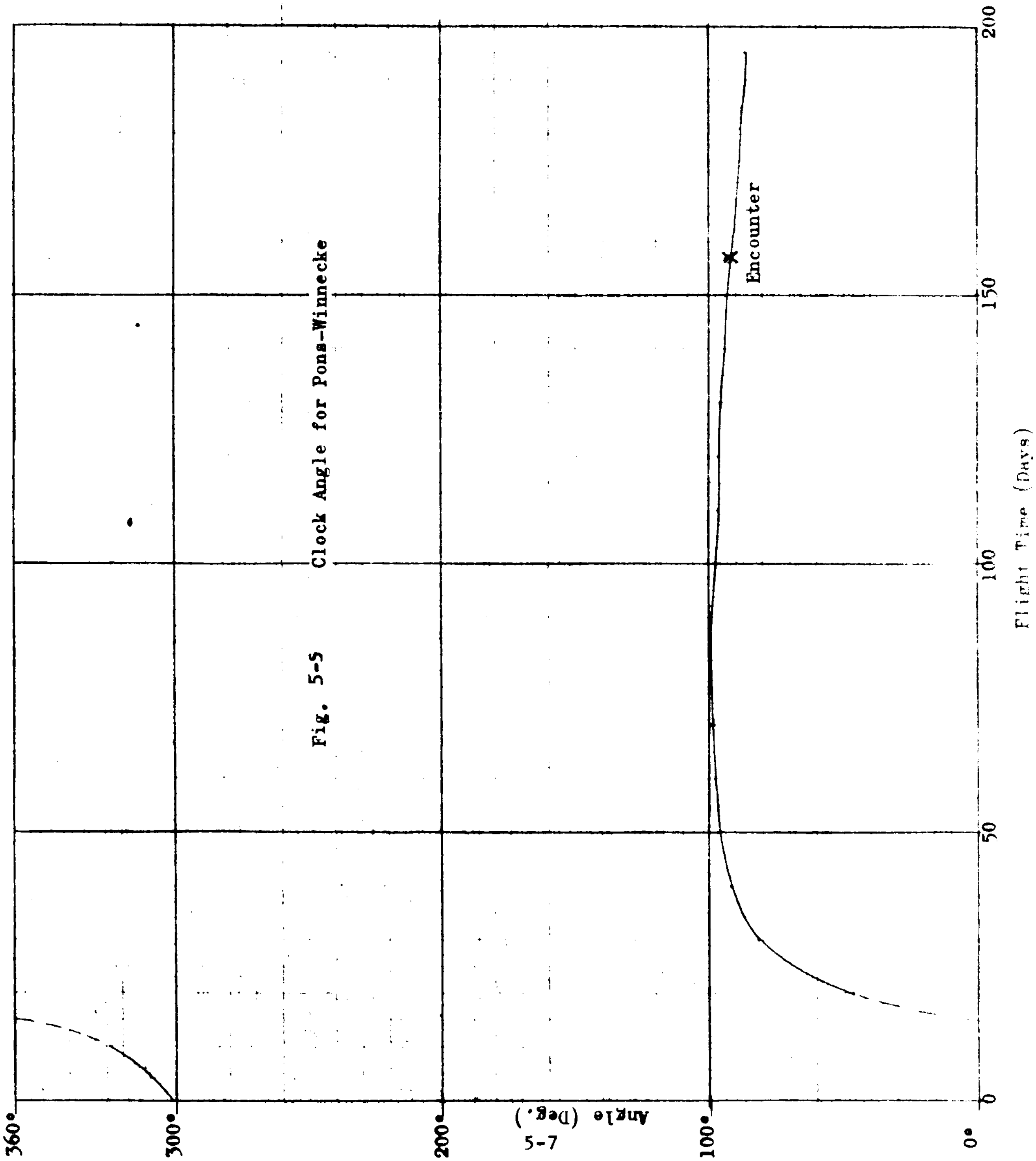


Fig. 5-5 Clock Angle for Pons-Winnecke

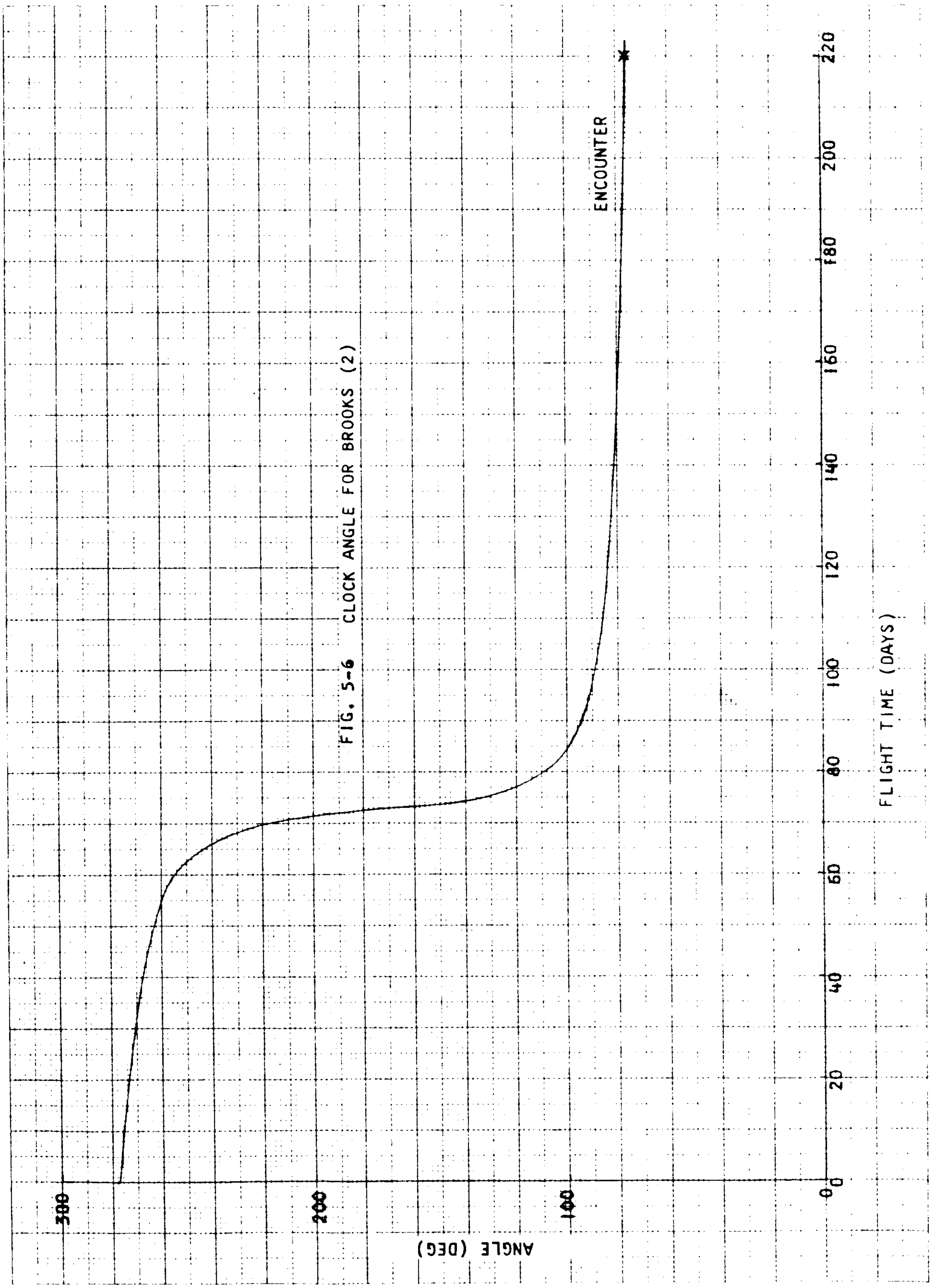


FIG. 5-6 CLOCK ANGLE FOR BROOKS (2)

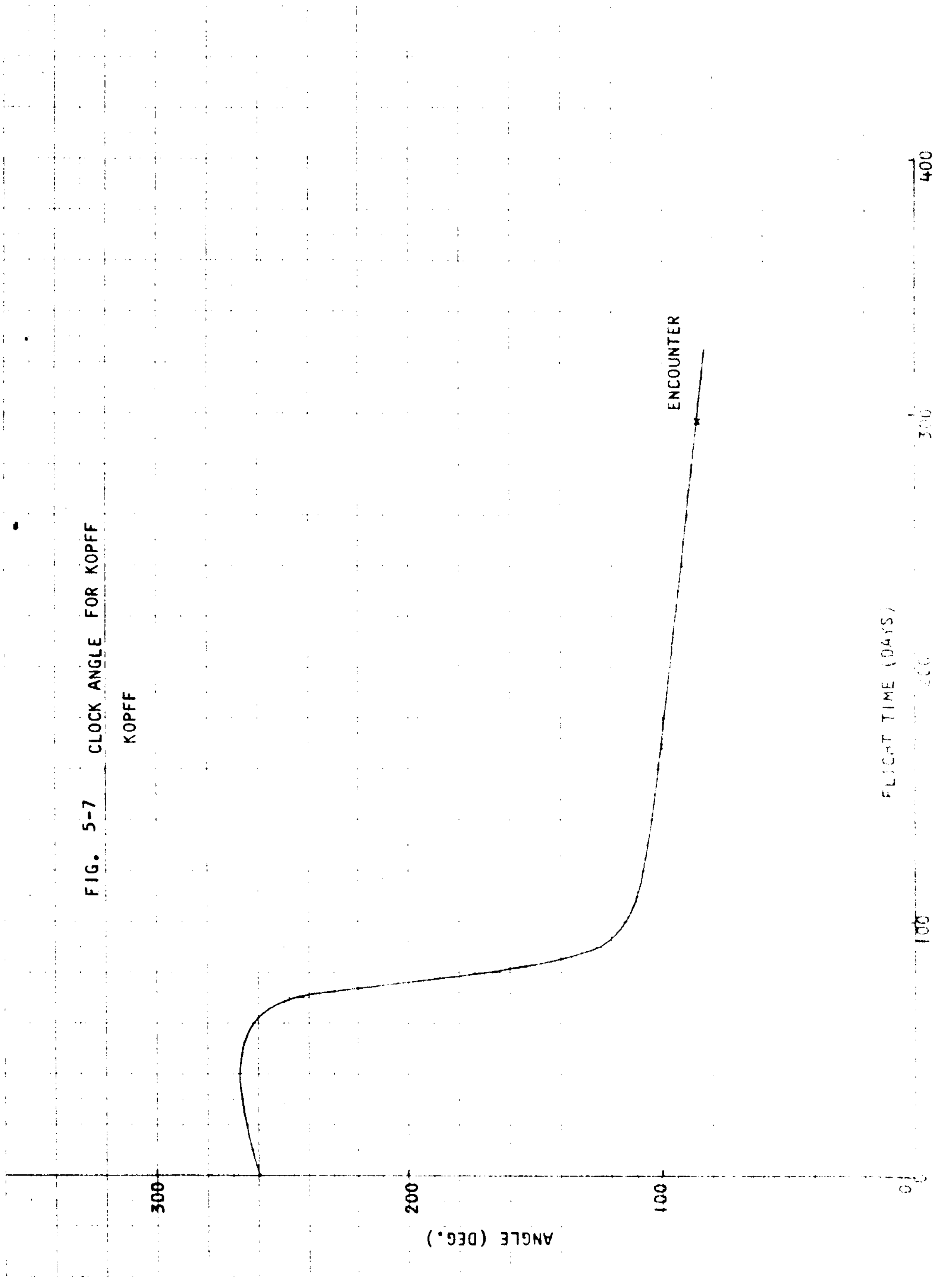


FIG. 5-7 CLOCK ANGLE FOR KOPFF

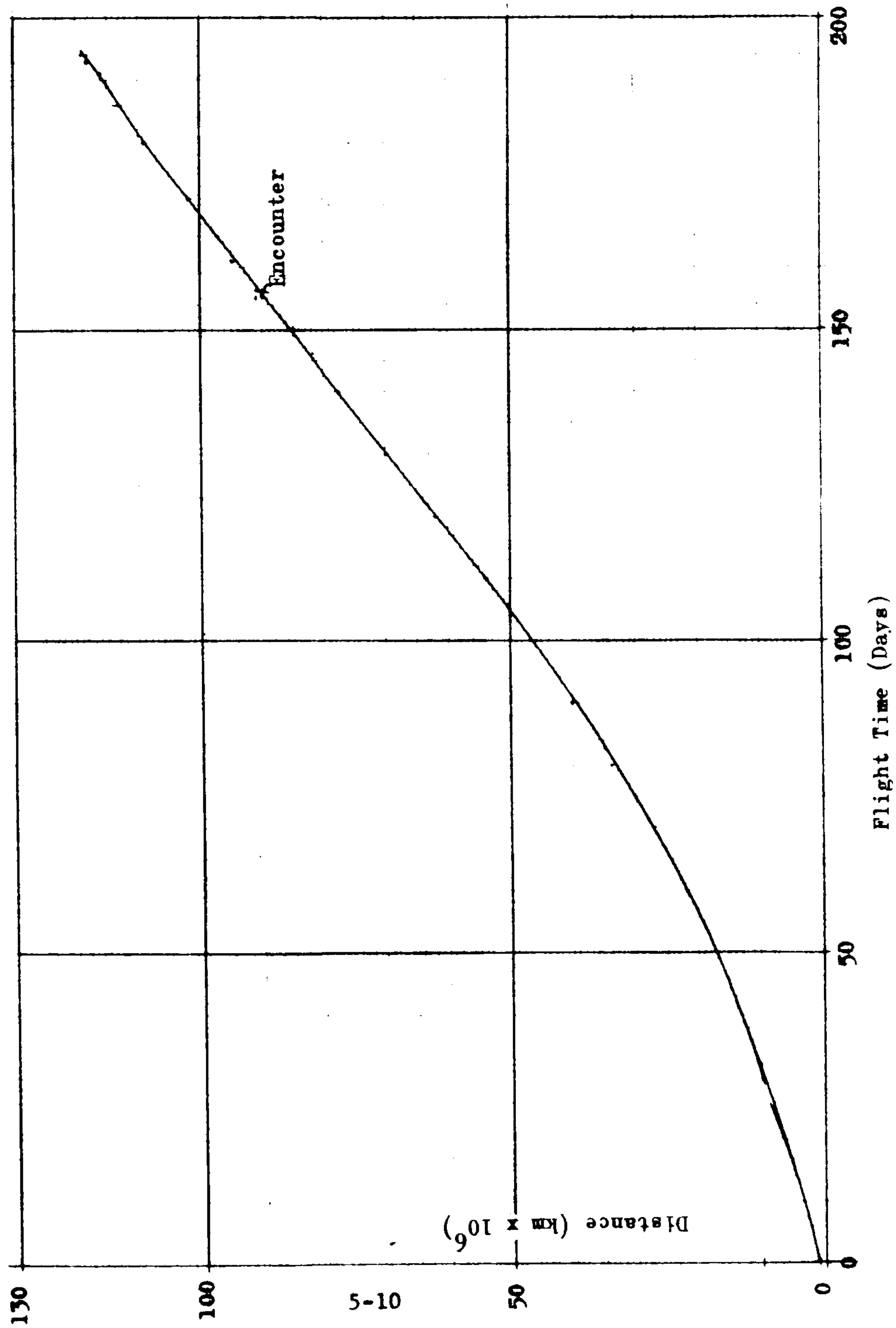


Fig. 5-8 Communication Range for Pons-Winnecke

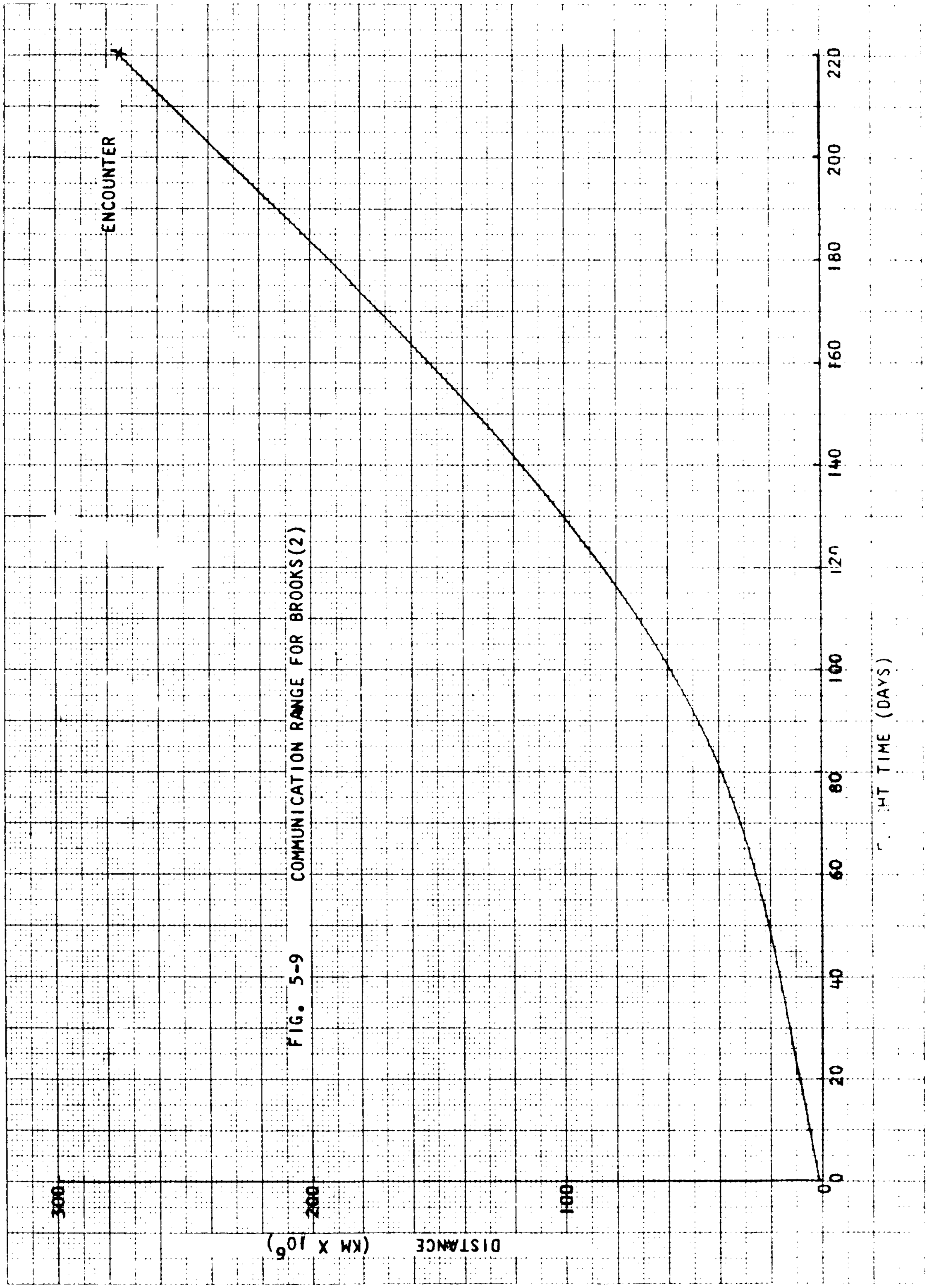


FIG. 5-9 COMMUNICATION RANGE FOR BROOKS(2)

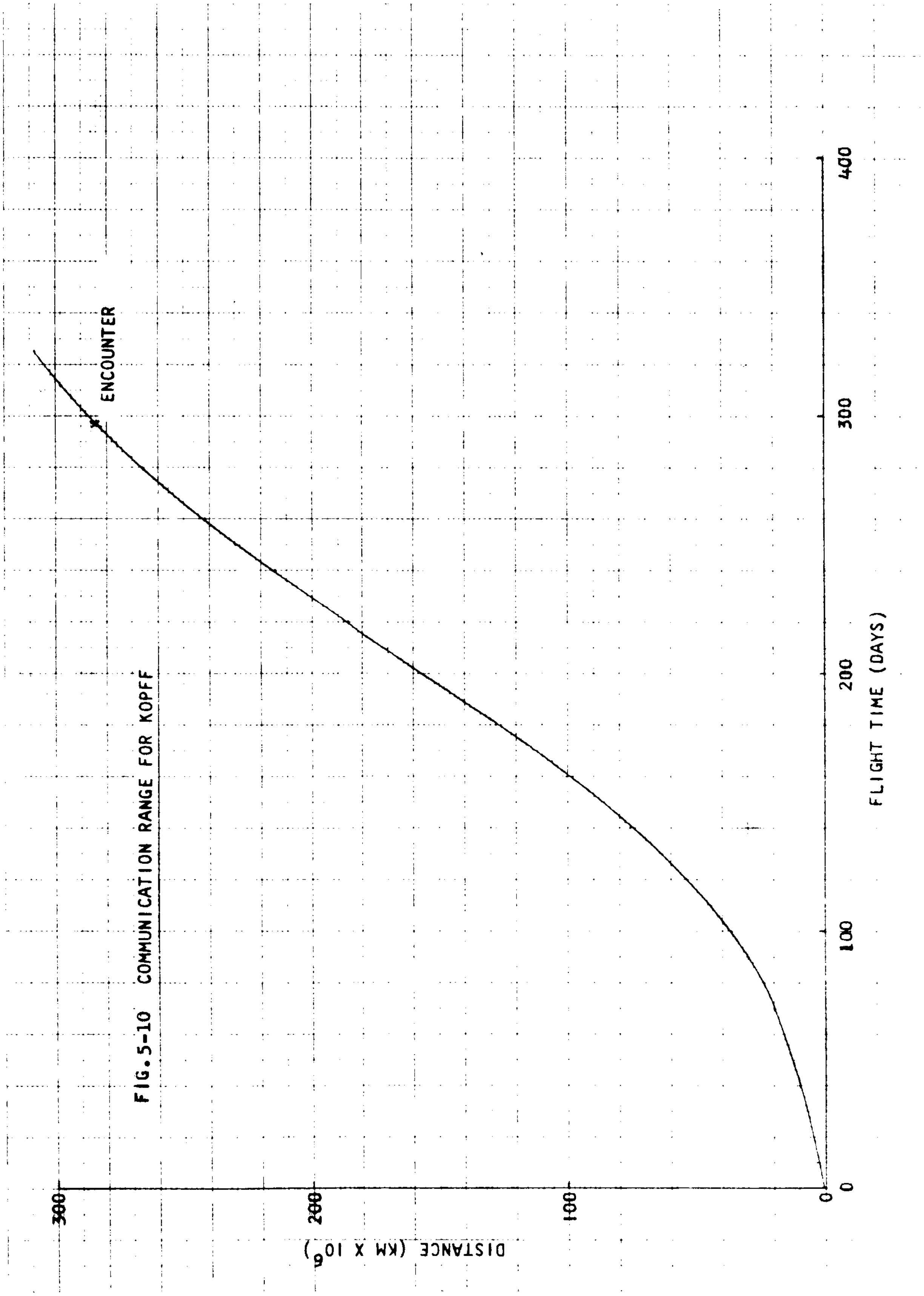


FIG. 5-10 COMMUNICATION RANGE FOR KOPFF

The feed for the waveguide is a conical spiral at the opposite end. This design has two shortcomings. First, the waveguide diameter is too large, allowing the higher mode to propagate and thus decreasing the transmission efficiency. Second, a simpler feed structure can be used to establish circular polarization. A quarter-wave plate can be used in the waveguide, as indicated in Figure 5-11b.

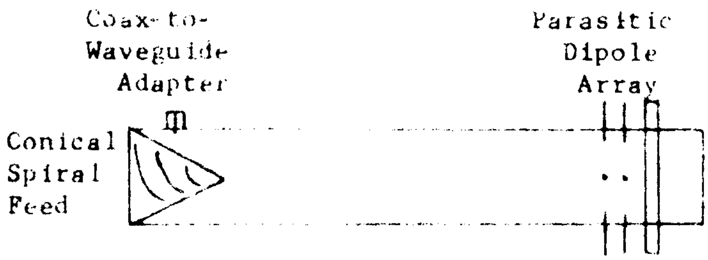
It is important that the omni antenna not be blocked by the spacecraft body nor by the solar panels in their stowed position. This will insure the reception of telemetry data should the panels fail to deploy on command. Hopefully, the telemetry will provide the reason for the failure and guide in its correction in future vehicles.

5.2 HIGH-GAIN ANTENNA

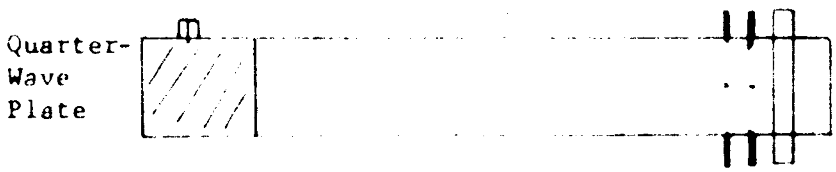
5.2.1 Pointing Angle Characteristics

Two types of antennas have been considered for providing the high-gain telemetry operation: a pencil beam and a fan beam. In either case, the angle information needed to define the antenna characteristics can be provided in three ways. In both cases, two direction angles with respect to the Sun-probe line can be used. One pair to use is the cone and clock angles as was used for the omni antenna. If a pencil-beam antenna is used, two-angle motion is required. If a fan beam is used, the cone-angle requirement can be covered by the fan-beam width. The clock angle, however, must be implemented by a rotation of the fan beam about the Sun-probe line, as shown in Figure 5-12a.

A second set of angles that can be used is the cone angle and the Angle A as shown in Figure 5-12b. The Canopus roll reference is a reasonable reference for aiming the antenna. Figure 5-13 indicates the geometry Angle B is defined as the angle between the Sun-probe and Canopus lines Angle A is the difference between these two angles. Picture one plane

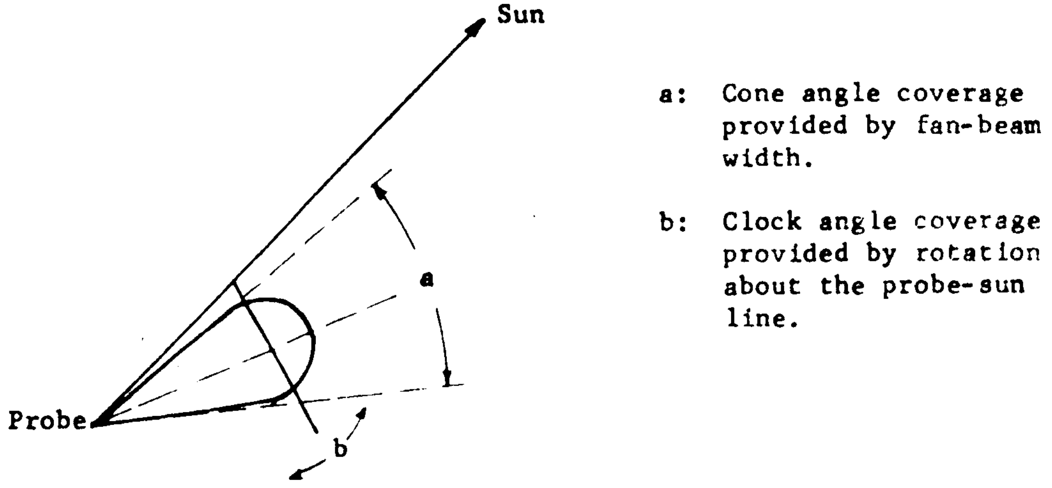


(a) Present Antenna

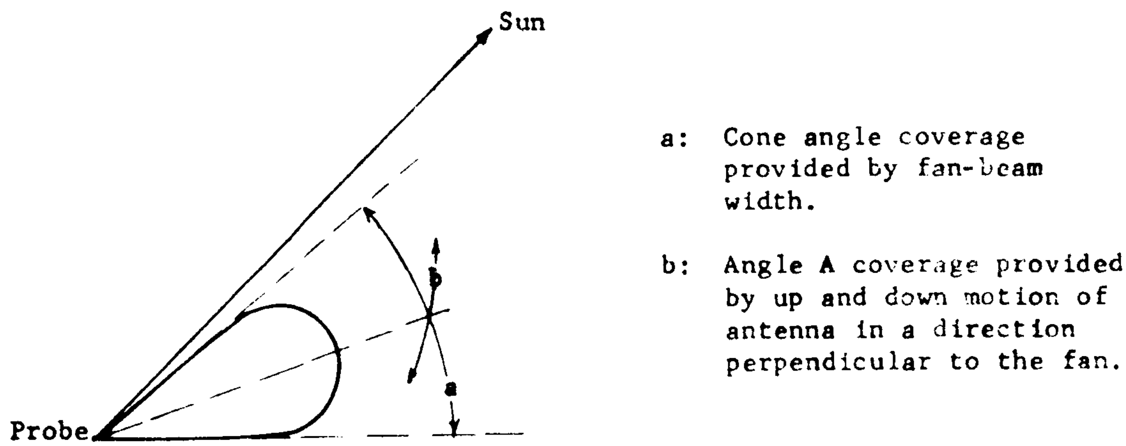


(b) Recommended Antenna

FIG. 5-11 Omni Antenna Configuration



(a) Cone and Clock Angles



(b) Cone and Angle A

FIG. 5-12 Antenna Pointing Angles

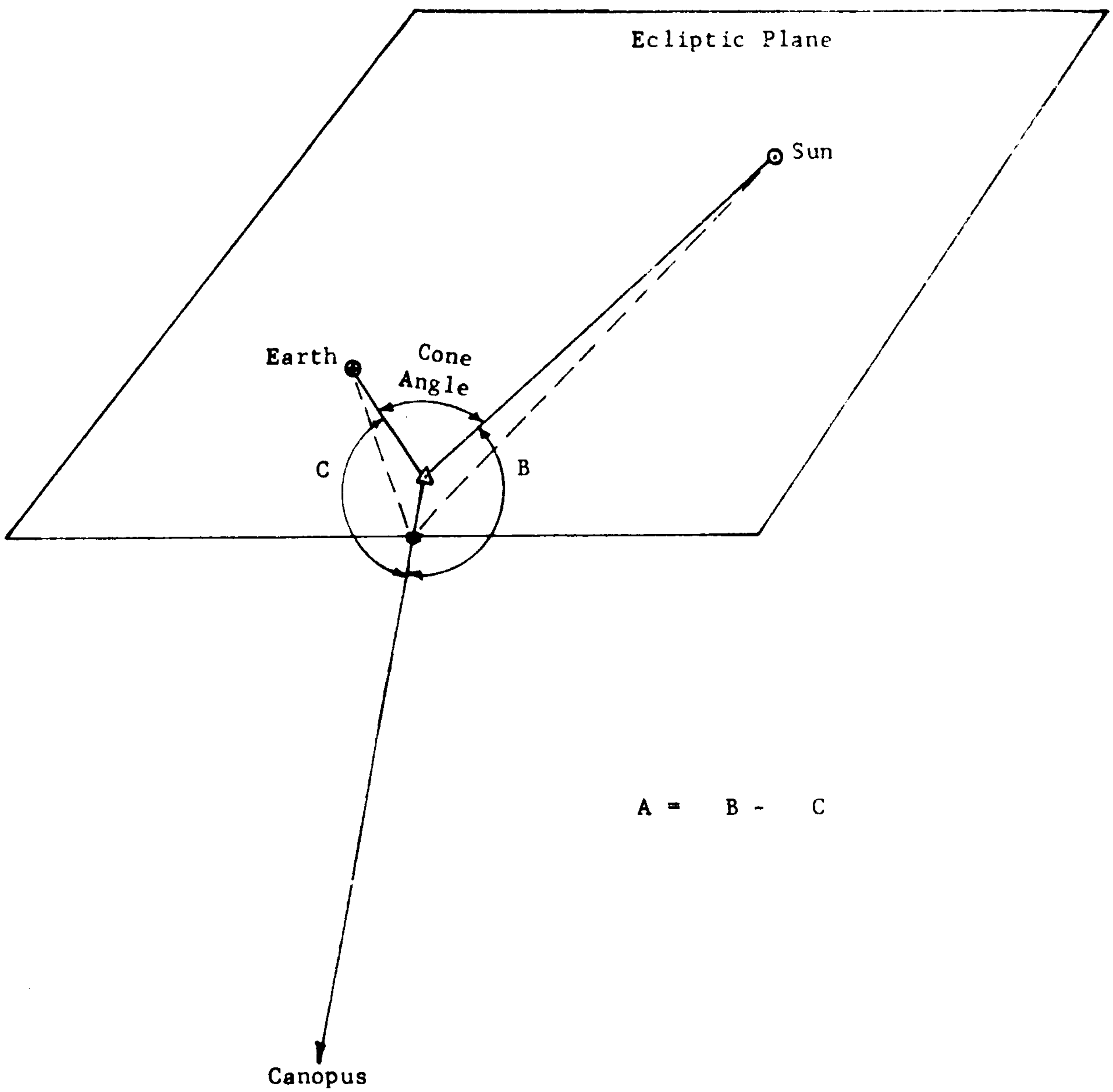


FIG. 5-13 High-Gain Antenna Aiming Geometry

containing the probe-Sun line and perpendicular to the Sun-probe-Canopus plane. Picture a second plane containing the Earth-probe line and perpendicular to the Earth-probe-Canopus plane. For small cone angles (viz., 30°) the angle A is very nearly the angle between these two planes. This angle, therefore, must be the angular motion of the antenna down from the Sun line in order to be aimed in a plane containing the Earth. This motion will occur in the Canopus-probe-Sun plane. Now, if a pencil beam is rotated perpendicularly to the Canopus-probe-Sun plane by an angle equal to the cone angle, the beam will be directed at the Earth. It is realized that this is only approximately true. However for the range of angles under consideration, it may be seen that the approximations are adequate for arriving at a good definition of the antenna-pointing requirements. Figures 5-14, 5-15, and 5-16 are plots of angle A variation. Figure 5-12b indicates the antenna motion using these angles.

As was shown in the telemetry system discussion, if a fan beam as broad as the Mariner-C beam is used, it will cover the cone-angle variation quite well in every case. The motion of Angle A is more difficult to compensate, especially in the case of Kopff and Brooks (2), if a very narrow fan beam is used. Consider the Angle A for Kopff in Figure 5-16. If a fan beam derived from a 6-foot dish is used, its 1 db points occur at 3°. This requires that at least 3 fixed positions be provided in which the antenna can be aimed. A pencil beam has the same aiming requirements as a fan beam in the Angle A direction. In this case, the aiming requirements, as determined by the cone angle, require that aiming positions be provided every 3° if a 6-foot dish is used.

The third method of defining antenna requirements and the method that must be used in order to define the exact requirements also utilizes the cone angle. The second angle is an angle away from a plane containing the probe-Sun line and the 90 clock angle line and in a direction

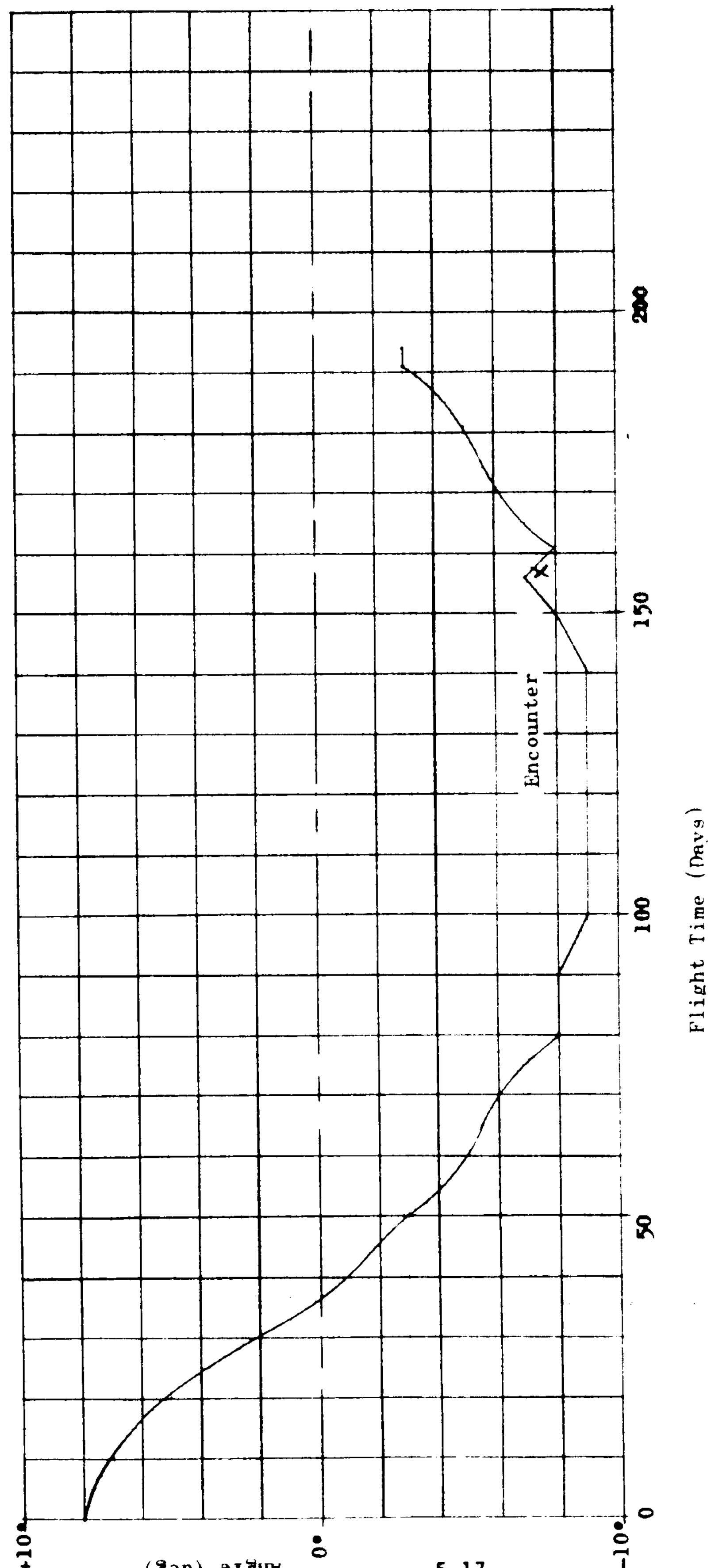


Fig. 5-14 Angle A - Pons-Winnecke

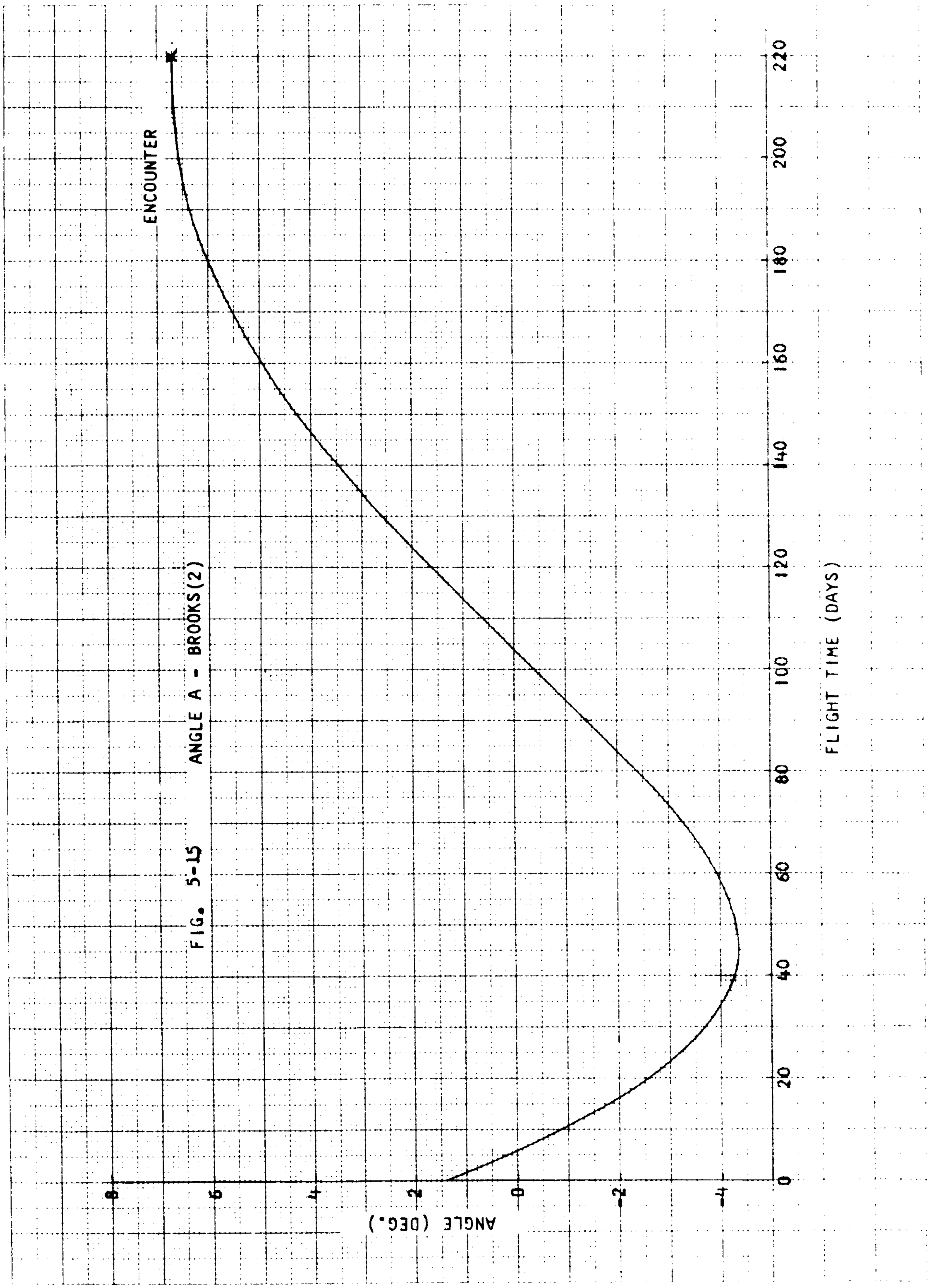


FIG. 5-15 ANGLE A - BROOKS(2)

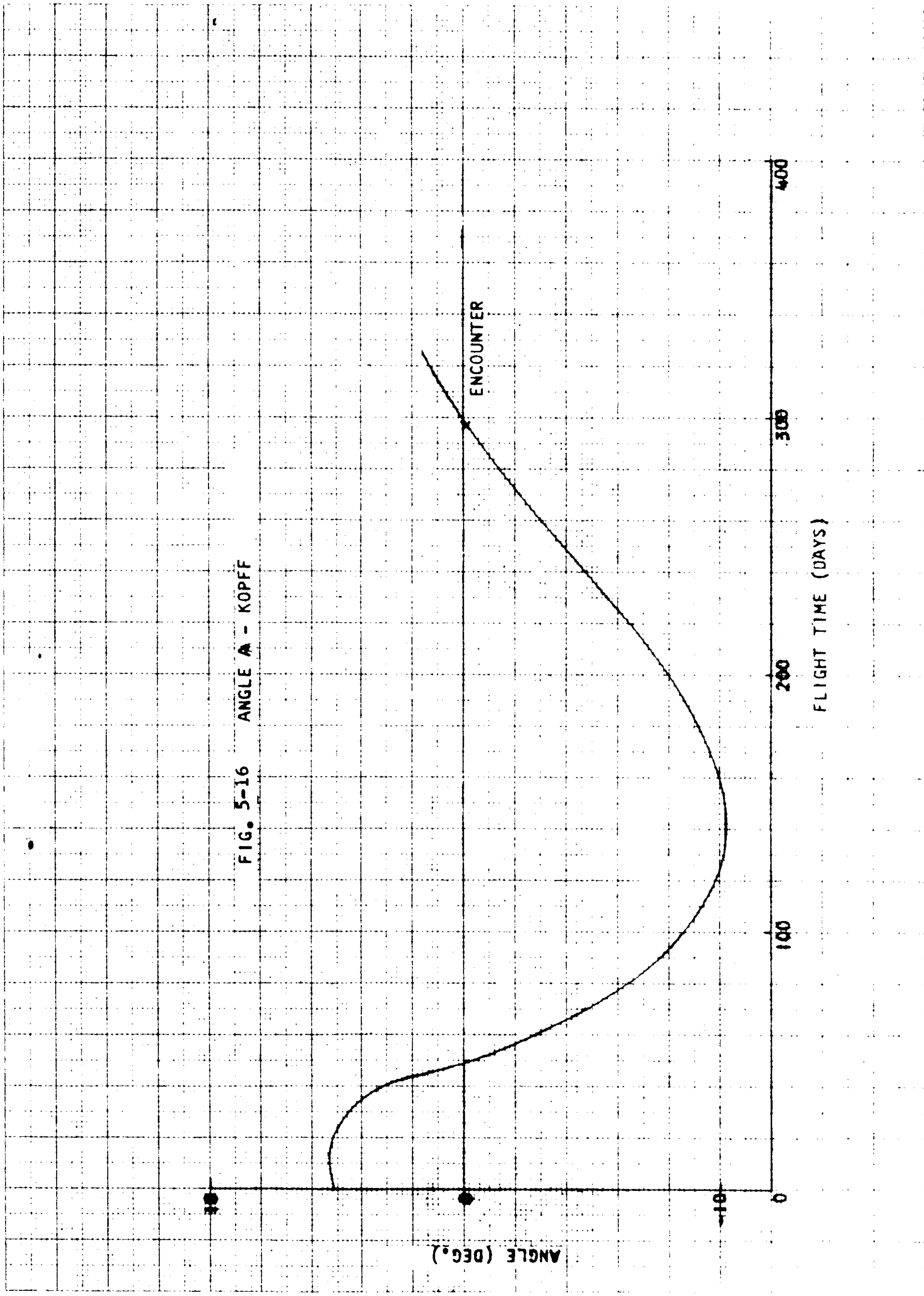
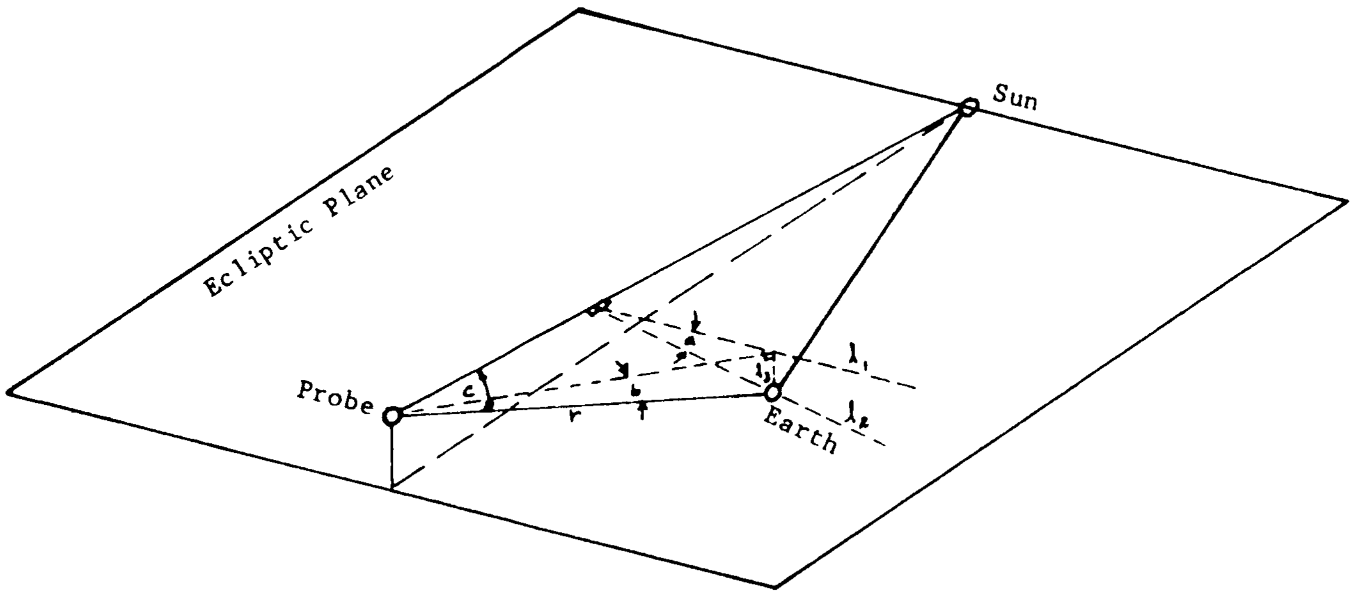


FIG. 5-16 ANGLE A - KOPFF

perpendicular to it. In order to define this angle exactly, it cannot be calculated as was Angle A, but must be calculated as shown in Figure 5-17. The clock angle minus 90° is shown as Angle a. Both of the lines $_1$ and $_2$ defining Angle a are perpendicular to the probe-Sun line. Line $_1$ defines the 90° clock angle. Angle b represnets the clock angle motion of the Earth as seen from the probe. If $_3$ is defined as the perpendicular to $_1$ from the Earth, the relationships indicated on Figure 5-18 follow.



$$l_3 = l_2 \sin a = r \sin b$$

$$b = \sin^{-1}\left[\frac{l_2}{r} \sin a\right]$$

$$l_2 = r \sin (c)$$

Therefore $b = \sin^{-1}\left[\sin c \sin a\right]$

r = probe-Earth range

c = cone angle

FIG. 5-17 Angle b Derivation

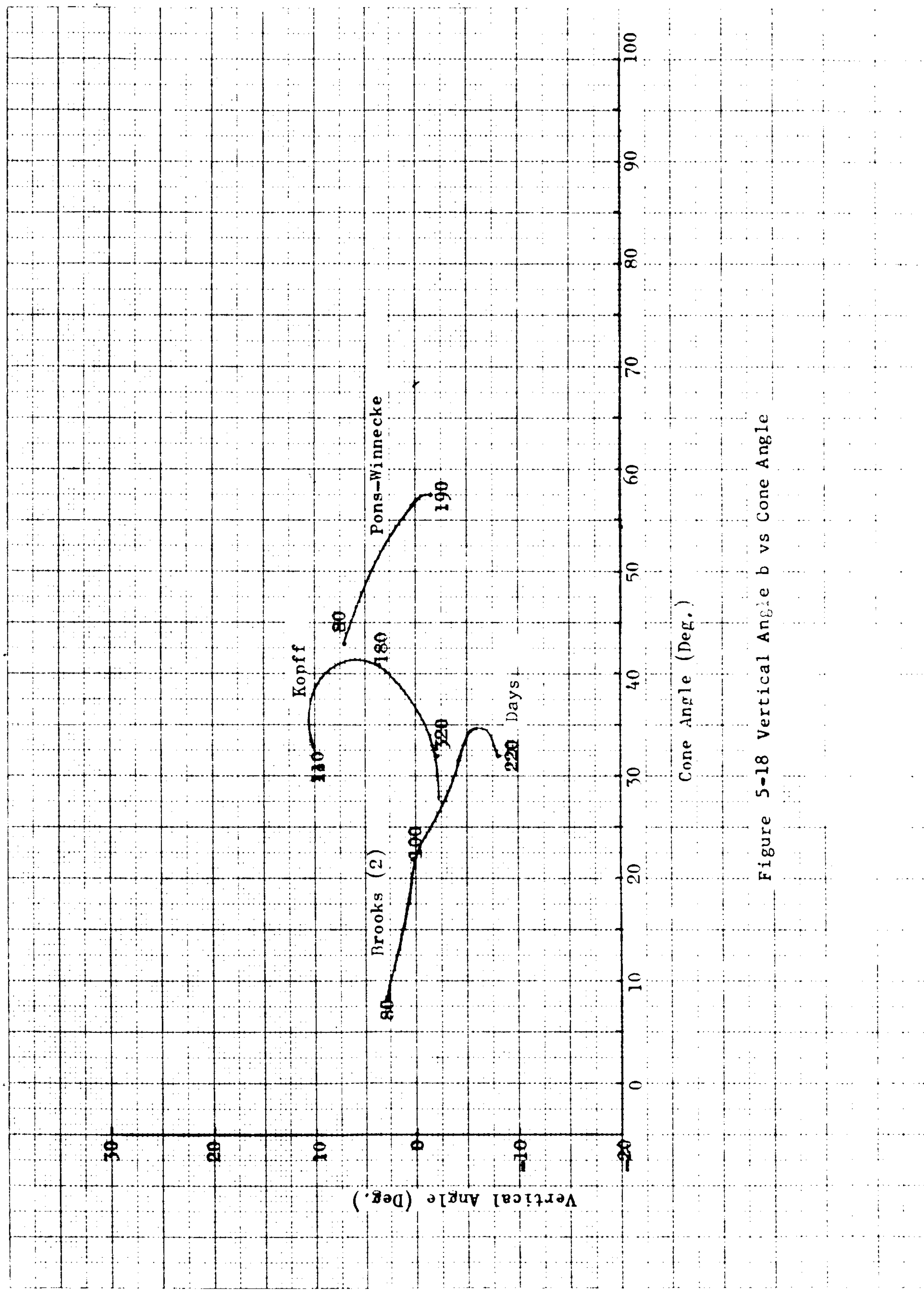


Figure 5-18 Vertical Angle b vs Cone Angle

SECTION 6
MICROELECTRONICS

6.1 APPLICATION TO COMET PROBE

The following Comet Probe subsystems are characterized by the relative ease in which that can be totally or partially implemented utilizing microelectronic techniques:

1. Command Detector
2. Command Decoder
3. Central Computer and Sequencer
4. Data Encoder
5. TV Subsystem Picture Data and Control Channels

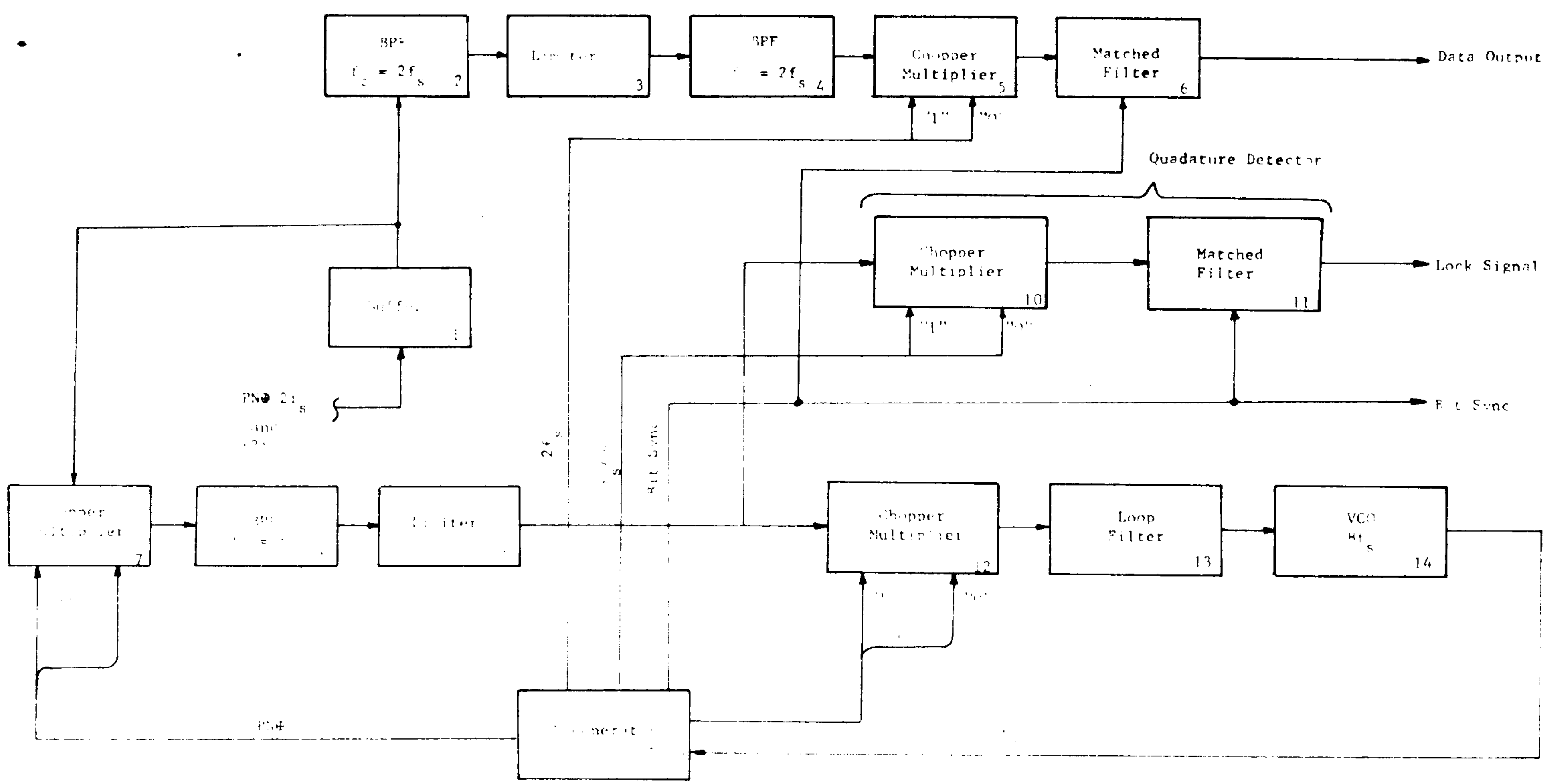
Other Comet Probe equipments such as those related to communication and power generation and distribution do not lend themselves to be easily implemented with microelectronics if the period 1967-1975 is considered.

One particular subsystem, the command detector, will be discussed at length and will serve to demonstrate the applicability of microelectronics to a system that is characterized by both digital and analog circuits operating at moderate speeds.

6.2 COMMAND DETECTOR

The Command Detector Block Diagram is shown in Figure 6-1. The system is characterized by the following features:

1. The amount of digital circuitry is approximately equal to the amount of analog circuitry.
2. The digital circuitry switching speed requirement is very moderate and is on the order of a kilocycle or less.



BPF
$f_c = 2f_s$ 2
3
BPF
$= 2f_s$ 4
Chopper
Multiplier 5
"1"
Matched
Filter 6
Data Output
Quadature Detector
Chopper
Multiplier 10
"1"
Matched
Filter 11
Lock Signal
Bit Sync
$2f_s$
Bit Sync
7
Chopper
Multiplier 12
Loop
Filter 13
VCO
$8f_s$ 14

3. The analog circuitry has a considerable amount of accuracy required. In several of the circuits, DC components are essential to successful operation. This formulates the need for low DC drifts.

4. In some areas, such as the bandpass filters, stable DC components are required.

5. Reliability is of paramount importance.

6. Power consumption should be as low as possible.

The most applicable area which can be implemented with microelectronics is the digital circuitry. Utilizing microelectronics, the following advantages are immediately realized:

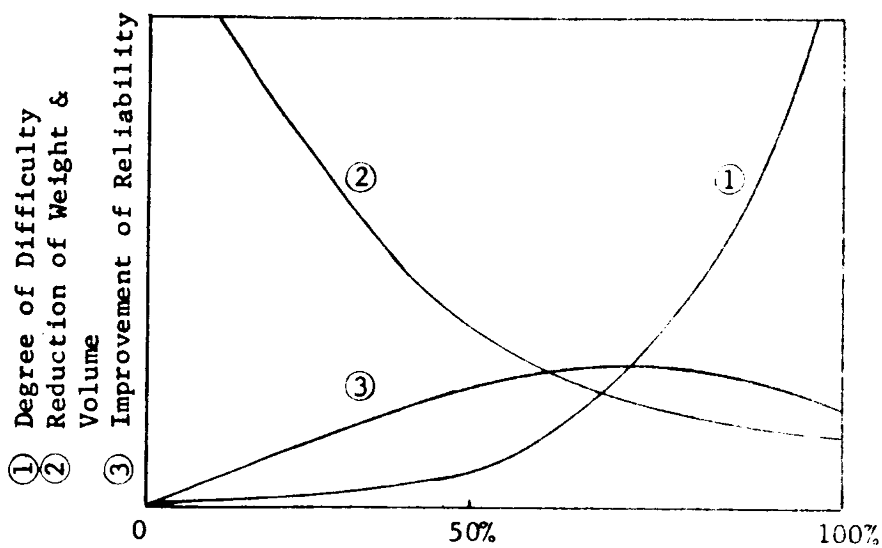
1. Approximately 50% of the original weight, volume and power is reduced by approximately 90%.

2. Reliability is increased if reliable digital circuit elements are utilized.

Characteristics 2, 5, and 6 previously listed define the requirements of the compatible logic family that should be utilized. Several existing logic families can simultaneously meet these requirements. [illegible] examples are the Texas Instrument Minuteman Networks and the Fairchild Milliwatt Logic circuits.

The ease with which the different analog circuits can be implemented by microelectronics varies from easy to hard, depending upon the particular circuit. For example, circuits are now available that can directly be used for the buffer. On the other ahnd, the components required to form the frequency characteristics of the band-pass filters are not available at present.

The recommendation is not to try to implement the total analog circuits with microelectronics; rather, only those that could be implemented by present, well-proven techniques that provide reliability advantages should be attempted. Considering both the requirements of all the Command Detector circuits and the present state-of-the-art one would probably develop the following chart:



The discontinuities in the three curves represent the point (50%) at which all digital circuits are implemented with microelectronics while the analog circuits are still conventional components. The fall-off in the reliability curve (Curve 3) represents the fact that the techniques are progressively becoming more difficult, eventually exceeding the state-of-the-art at 100%. There would be a considerable reliability advantage if many circuits of the same type were utilized in the analog section. This advantage derives from the fact that in a given amount of time, more testing to determine reliability can be accomplished for a few circuits than for many circuits.

Reviewing the analog requirements, it can be seen that essentially only one circuit can be utilized several times. This would be an integrated-circuit amplifier (ICA) with the following parameters:

(a) Differential input

(b) DC-coupled

(c) Offset referred to input < 10 m v

(d) DC drift referred to input < 10 $\mu v / ^\circ c$

(e) Open-loop gain > 40 db

(f) Open-loop input impedance in the order of a few kilohms

(g) Open-loop output impedance on the order of a few hundred ohms

(h) Open-loop gain margin in the order of 10 db.

Several available integrated-circuit amplifiers meet the majority of these requirements. One in particular, the Fairchild μA702, appears feasible. Others developed by Signetics and Motorola may suffice.

The Command Detector shown in Figure 6-1 has several types of analog circuits, some of which are repeated:

Circuit	No. Required
Band-Pass Filter	3
Limiter	2
Buffer	1
Chopper Multiplier	4
Loop Filter	1
VCO	1
Matched Filter	2

Each of these circuits is analyzed below in terms of its requirements and possible microelectronic versions.

Estimated Weight, Volume and Power

The following assumptions are made:

(a) The ICA is a TO-5 package.

(b) All thin-film networks are housed in TO-5 packages.

(c) All digital circuits are housed in small flat packages approximately 0.25" x 0.25" x 1/8".

With these assumptions Table 6-1 has been formulated to summarize the number of microelectronic package types. Allowing circuitry for power supply de-coupling, it is estimated that the entire Command Detector can be housed in two-thirds of a standard JPL 6 x 5 x 1 chassis. The resulting weight and volume are 1 lb and 22 cubic inches. Assuming a power dissipation of 7 mw/digital circuit and 40 mw/ICA, the total estimated power is 900 mw.

6.2.1 Input Buffer

The Input Buffer is shown in Figure 6-2. The buffer is the ICA with close to unity feedback which provides the required high input impedance and low output impedance. The thin-film resistor network is included to provide some gain if required. To protect the amplifer from input fault voltages, the zener arrangement is included. The resistors can be in the order of kilohms and need not be extremely precise. The buffer end-to-end is non-inverting.

6.2.2 Limiter

The Limiter is shown in Figure 6-3. The overall Limiter can be comprised of a pre-limiter which is a saturating ICA and a post-limiter that can be implemented wtih a combination of microelectronics and standard components.

6.2.3 Band-Pass Filter

The band-pass filter requirements are characterized by large Q, stability,

TABLE 6-1 Number of Microelectronic Package Types

	Buffer	Limiter	BPF	Chopper Multiplier	Matched Filter	Loop Filter	PN Generator & Logic Section	VCO	Total Number
Flat Packs	0	0	0	0	5	0	18	0	23
TO-5 Cans	2	1	2	4	3	2	0	0	14
Conventional Components*	1	10	6	2	3	2	0	20	44

*Includes transistors in TO-18 packages and 4 tantalytic capacitors

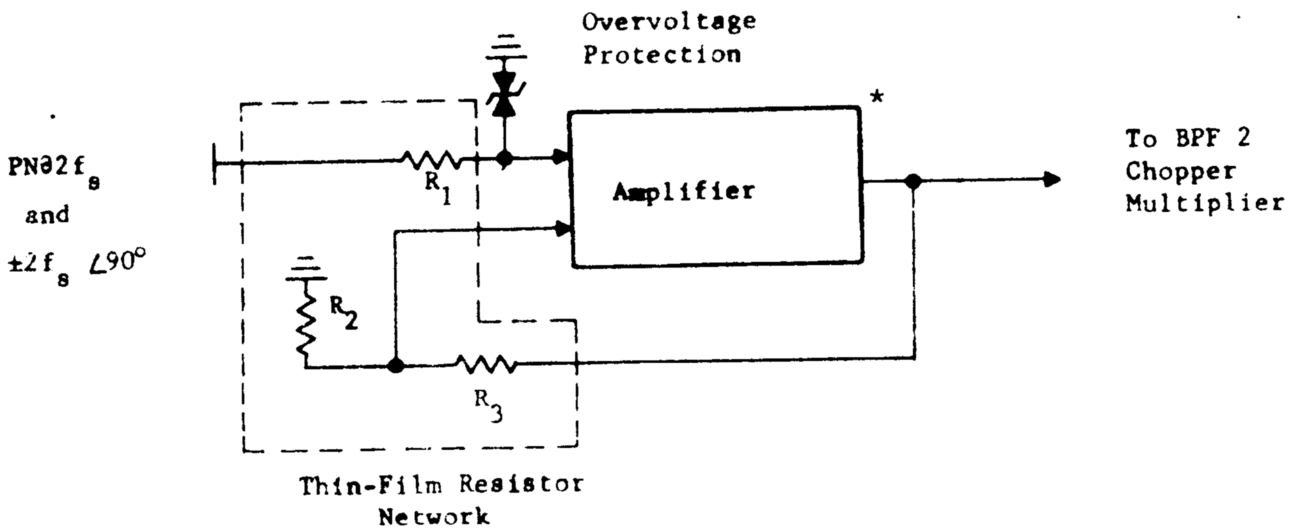
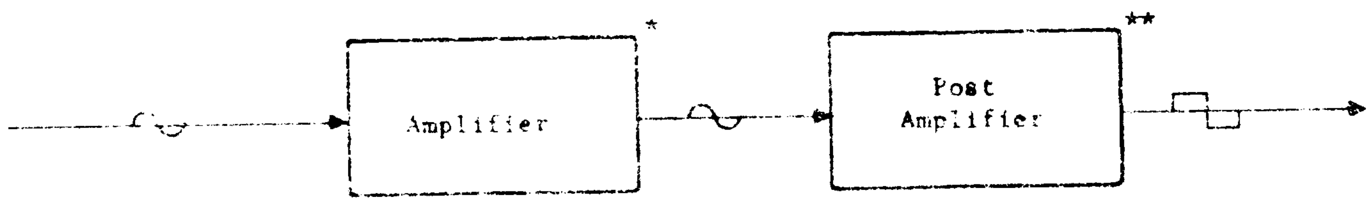


Fig. 6-2. Microelectronic Input Buffer



* Integrated Circuit Amplifiers

** Combination Conventional and Thin-Film Circuit

Fig. 6-3. Limiter

and a band-pass of several cycles. The center frequency is on the order of a kilocycle or less. This filter can best be implemented by an active filter that has frequency-independent gain in the forward path and a twin-tee circuit in the feedback path. This filter is shown in Figure 6-4 and 6-5. The Q is determined by the B feedback factor of the inner loop. Utilizing the ICA, the corresponding B is fixed by the resistors in the thin-film network. The stability and accuracy of the Q need not be more than a few percent. Hence, the requirements of the resistors is not stringent. The center frequency of the filter depends heavily on the components within the twin-tee filter. The required accuracy and drift of the components forbid the use of microelectronic components.

6.2.4 Chopper Multiplier

A microelectronic version of the chopper multiplier is shown in Figure 6-6. The ICA provides the complement of the input signal. The two chopper circuits select either Ein or -Ein for the output (the unselected component is shorted to ground). The selection is controlled by fs and its complement thus producing the signal "Ein x fs". This type of multiplier suffers an amplitude loss. However and additional ICA can be used to compensate for this loss.

6.2.5 Matched Filter

The microelectronic matched filter is shown in Figure 6-7. Integration is provided by the RC circuit which has a long time constant compared to the bit period. Dumping of the capacitor residue at the end of a bit period is accomplished by the chopper transistor. Sensing of the capacitor voltage is accomplished by the ICA which saturates at a predetermined value of input voltage. The indicated method of gating the

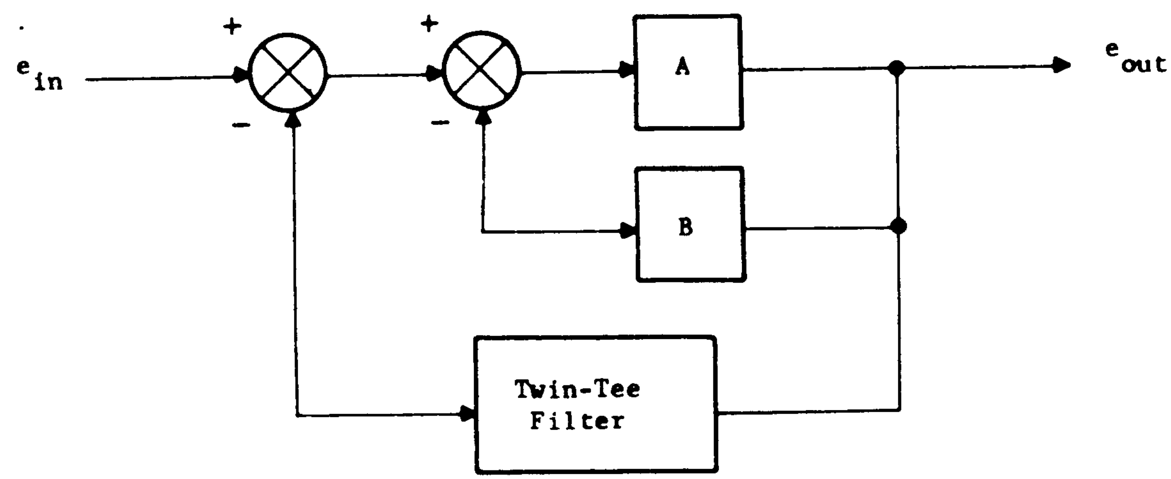


Fig. 6-4. BPF Block Diagram

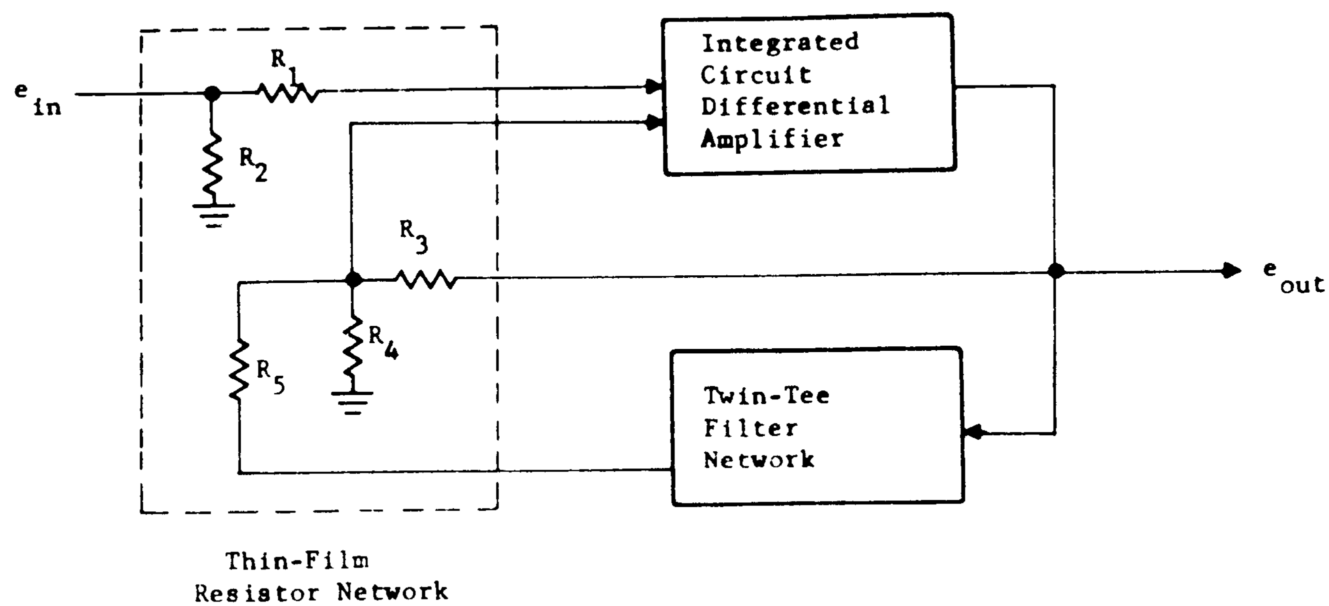
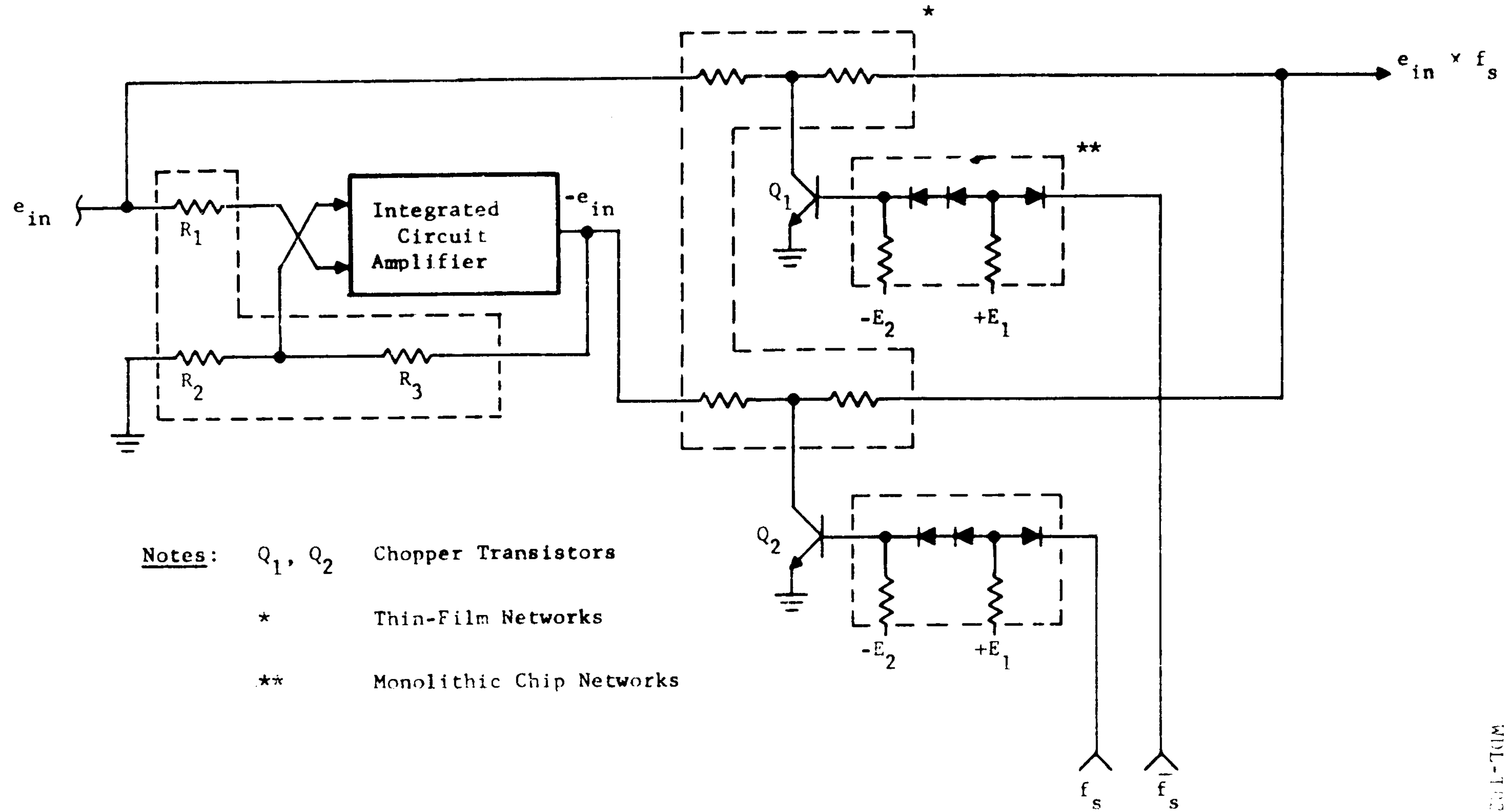


Fig. 6-5. BPF Utilizing Microelectronics



<u>Notes</u>: Q_1, Q_2 Chopper Transistors

* Thin-Film Networks

** Monolithic Chip Networks

Fig. 6-[illegible]. Chopper Multiplier

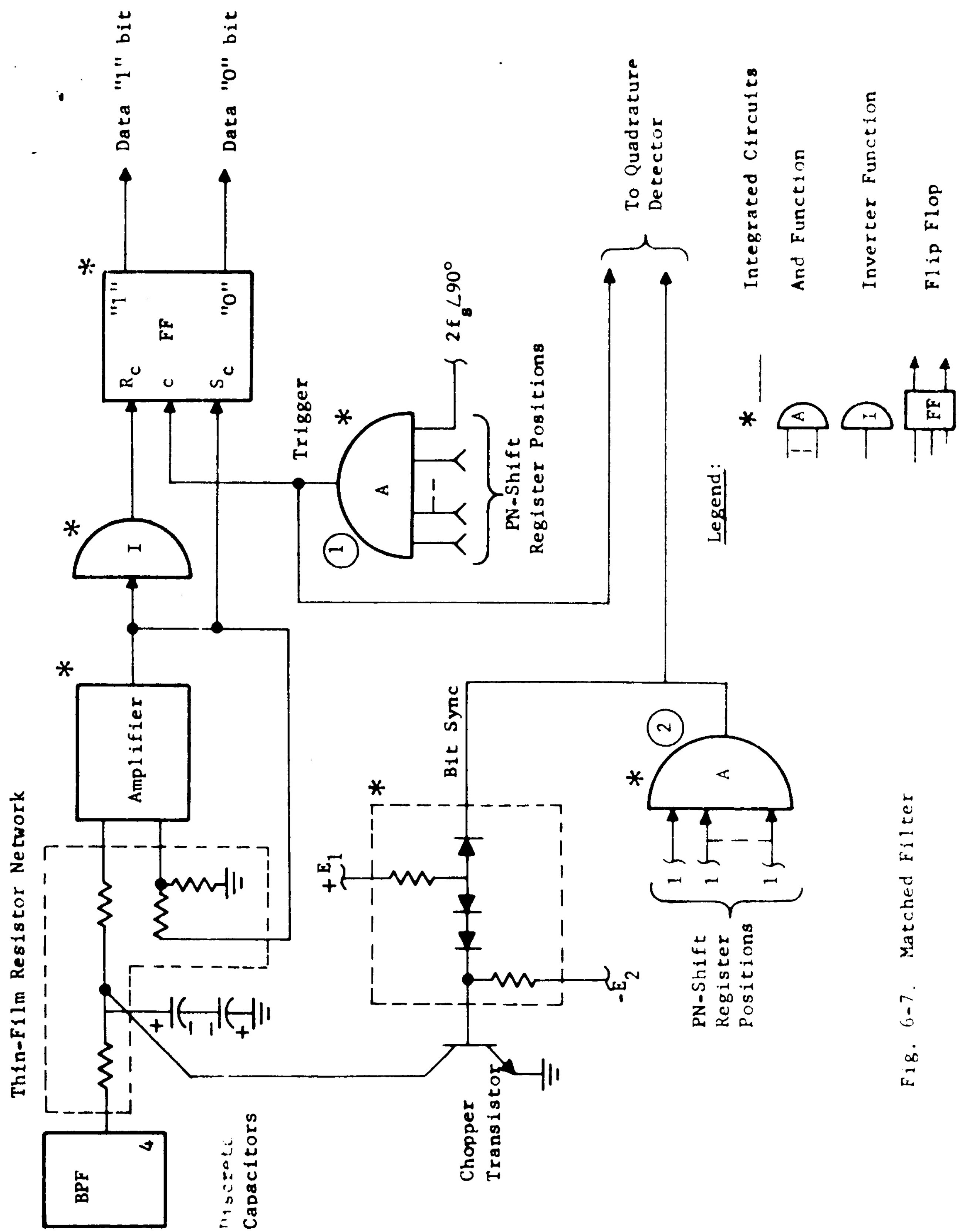
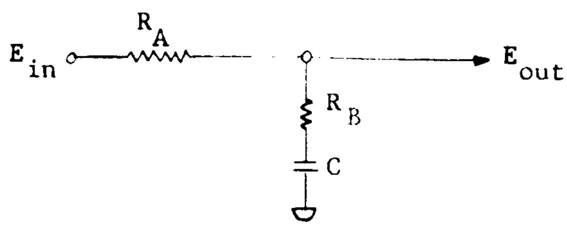


Fig. 6-7. Matched Filter

ICA output into the data flip-flop and the dumping of capacitor voltage eliminates the need for monostables which are susceptible to noise. The state of the PN generator just prior to bit sync is detected and strobed by AND 1 . The output of this circuit sets the flip-flop to the state determined by the ICA output. The bit sync, which occurs just after the flip-flop is triggered, is generated by AND 2. This signal provides the drive to the chopper which dumps the capacitor.

6.2.6 Loop Filter

The loop filter is essentially the following circuit:



The transfer function is

$$\frac{E_{out}}{E_{in}} = \frac{SR_BC+1}{S(R_A+R_B)C+1} \approx \frac{K\left(S+\frac{1}{R_BC}\right)}{\left(S+\frac{1}{R_AC}\right)}$$

The product R_AC is an exceptionally long time constant. R_A cannot be made as large as is necessary since it must include the input resistance of the loop filter. The value of C is limited by capacitor leakage. In order to achieve a product without the use of a large physical capacitor, the technique of capacitor multiplication is suggested. This circuit is shown in Figures 6-8 and 6-9.

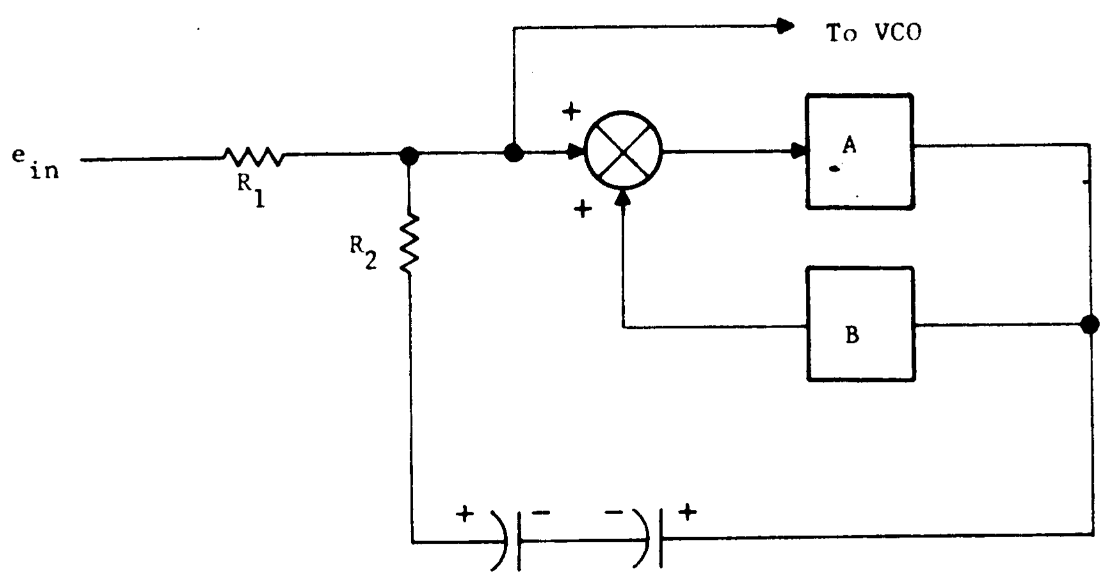


Fig. 6-8. Capacitor Multiplier Loop Filter

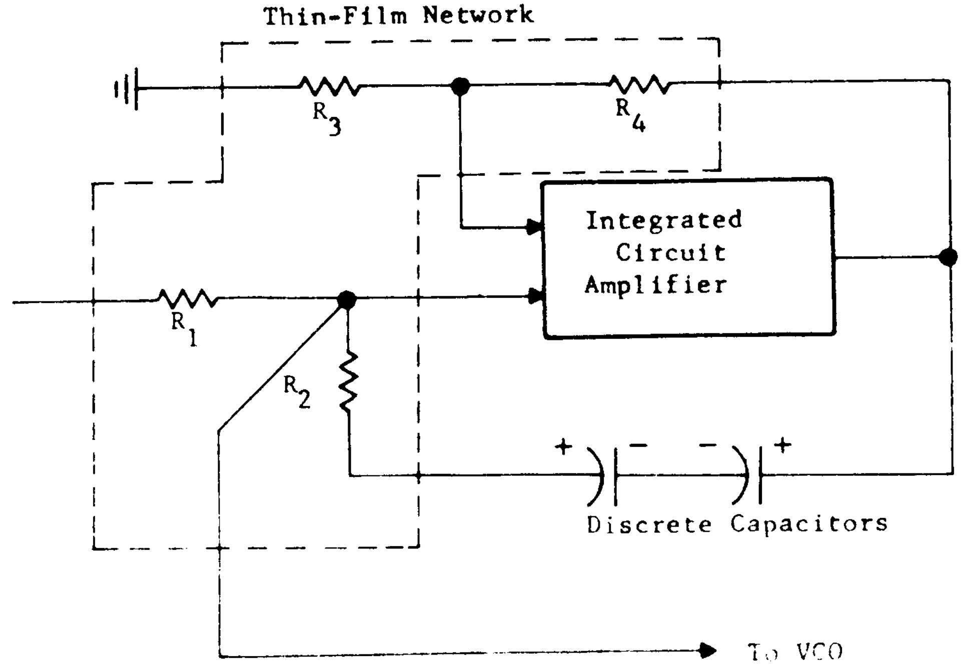


Fig. 6-9. Microelectronics Capacitor Multiplier Loop Filter

6.2.7 VCO

It is quite probable that the VCO can be built utilizing both micro-electronics and conventional components.

6.2.8 PN-Generator and Logic Section

All the digital circuit requirements can be met by the four integrated circuits shown in Figures 6-10, 6-11, 6-12, and 6-13. These circuits were not meant to represent a specific family of existing circuits. However, some existing circuits are very similiar to those shown. Utilizing integrated circuits, as possible configurations of the PN generator and logic section are shown in Figures 6-14 and 6-15.

6.3 DATA ENCODER

These areas, primarily digital, which can be implemented with micro-electronics, are listed below:

1. Pseudo-noise generators
2. Timing for the A/D converters
3. Timing for the time division multiplexing format
4. Rate generator
5. Miscellaneous digital circuits

The conversion of these areas to microelectronics is quite significant since they represent a large percentage of the Data Encoder. Philco WDL as well as other companies have developed Analog-to-Digital convertor almost entirely with microelectronics. Hence a microelectronic A/D converter is quite feasible for the Data Encoder. A large portion

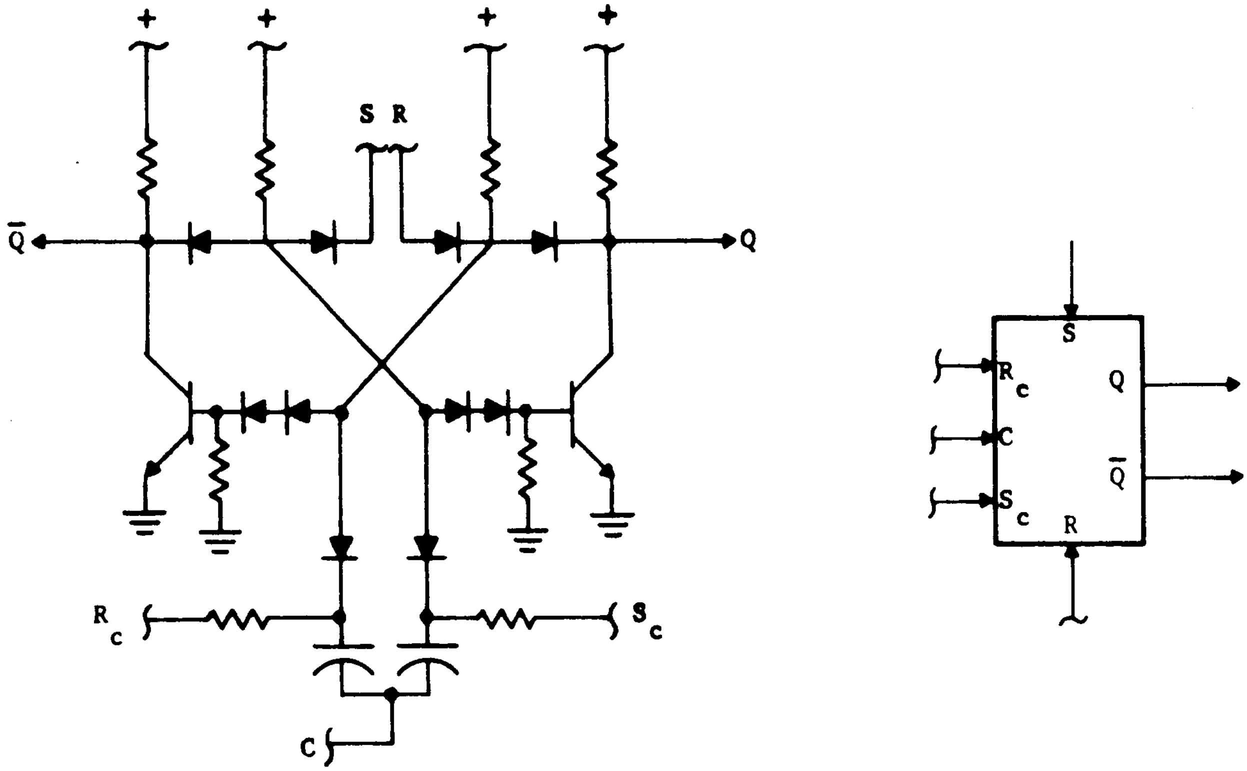


Fig. 6-10. Logic Flip Flop

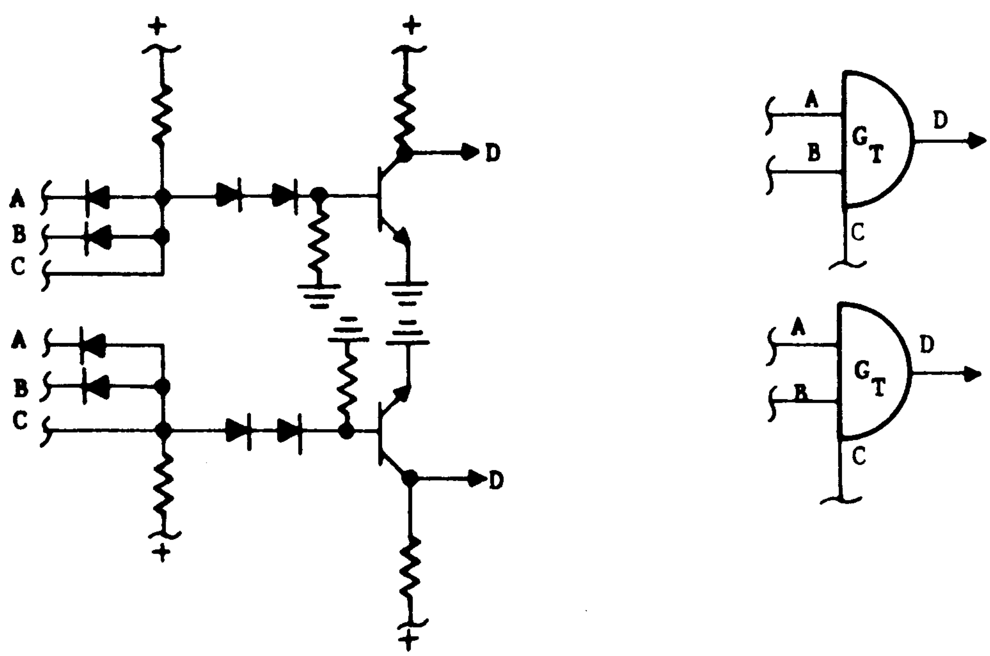


Fig. 6-11. Dual Two-Input Gate

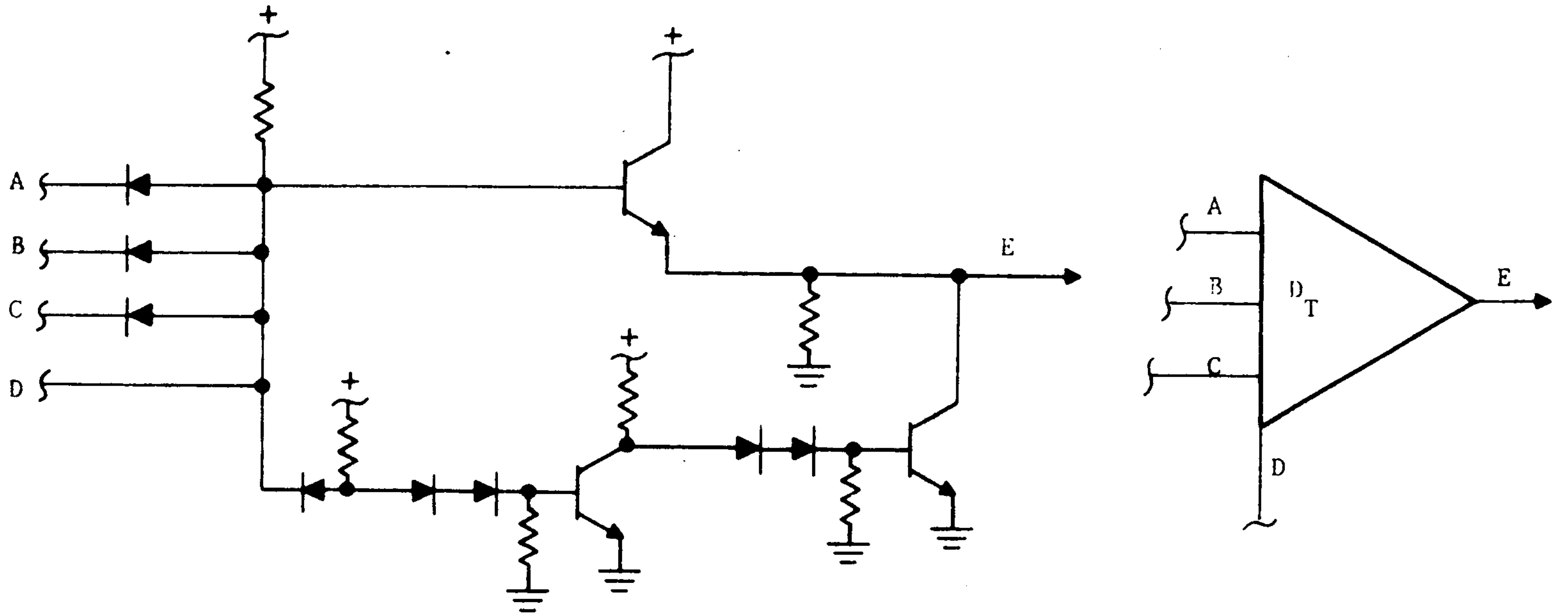
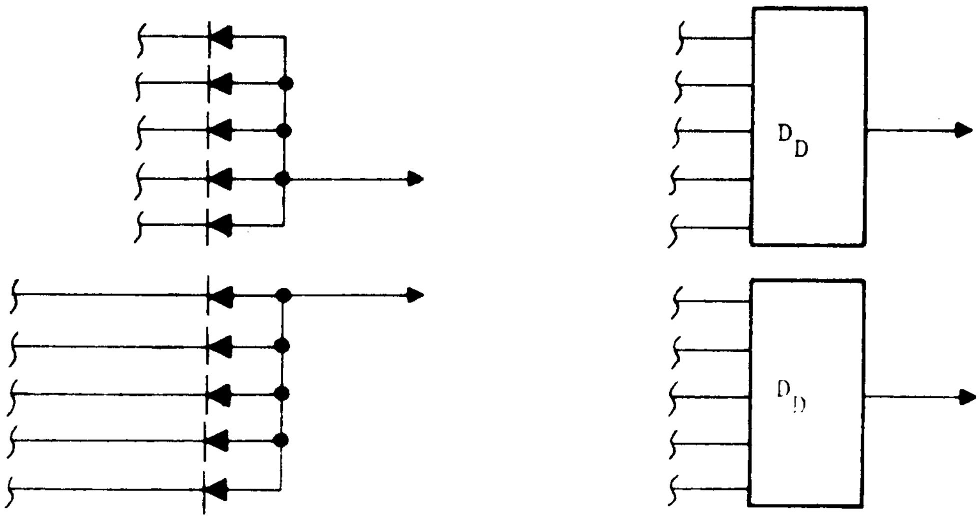


Fig. 6-12. 3 Input Driver



[illegible]-Gate [illegible]xtender

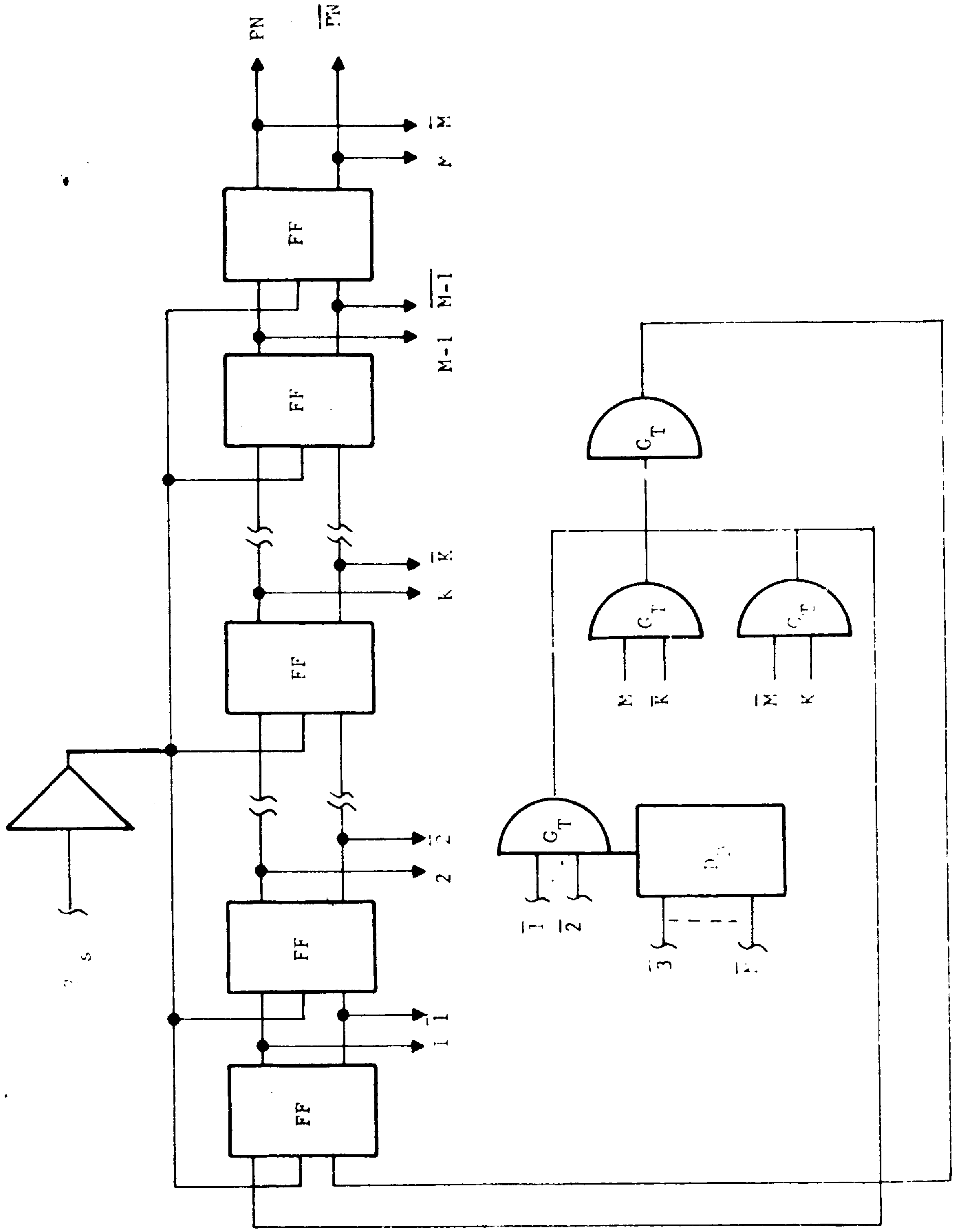


Fig. 6-16. PN Generator

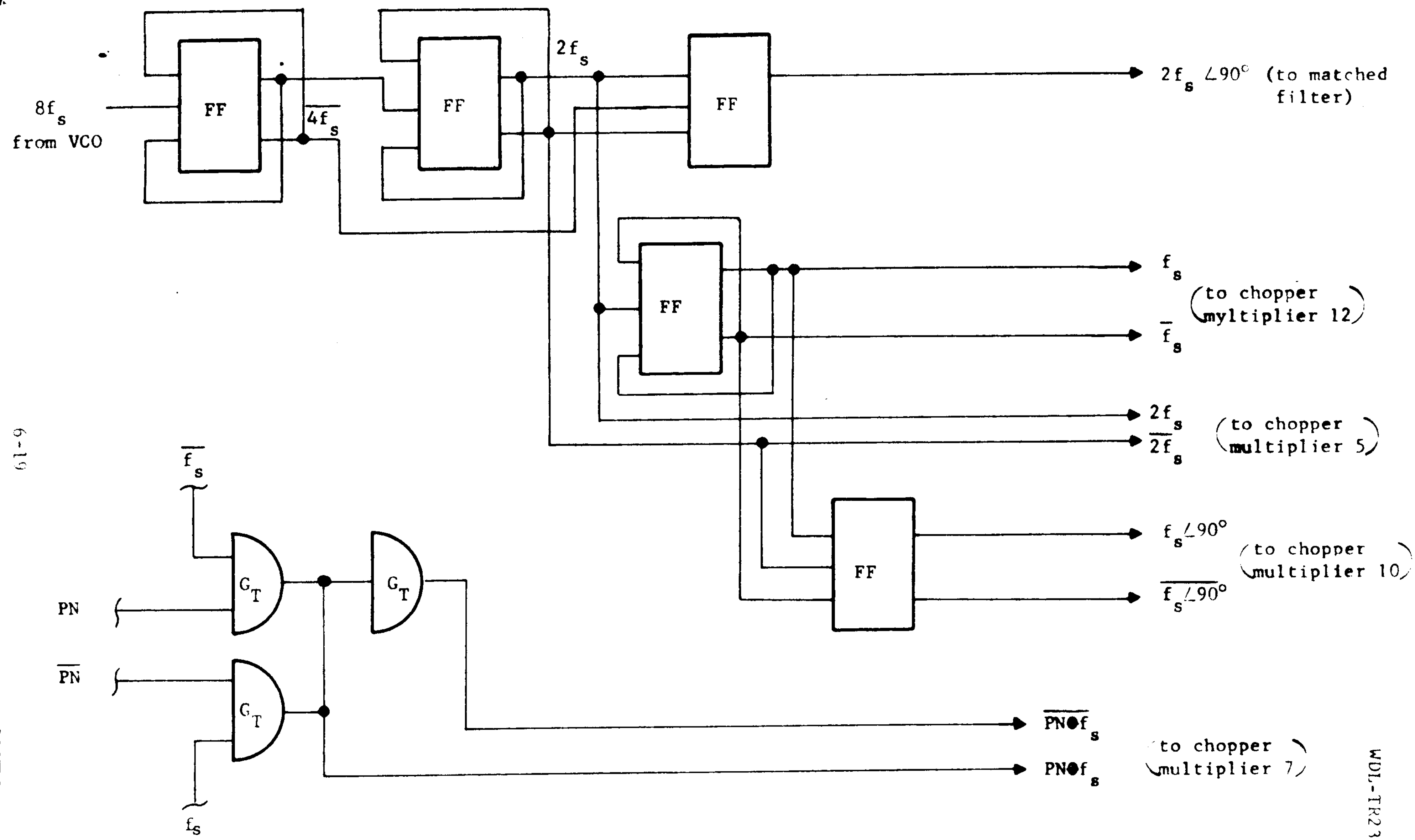


Fig. 6-15. Logic Section

of the Data Encoder is required for the multiplexing gates (analog switches). Recently Texas Instrument announced the availability of an integrated-circuit gate that could perform the multiplexing gate function. At present time IBM is developing an analog gate switch for the Telecommunication Group at JPL. As in the Command Detector, it may be quite feasible to employ an Integrated Circuit Differential Amplifier to implement various analog functions of the Data Encoder.

6.4 CENTRAL COMPUTER AND SEQUENCER

Since the CC & S is primarily digital, it is feasible to implement nearly the entire system with microelectronics. An exception is the output controls which require transfer relays. The logic circuits required to implement the CC & S design have two outstanding requirements: good noise rejection and low power. The good noise rejection is important since it is extremely important not to perturb the contents of the several registers which control the CC & S events. Low power is necessary because of the larger volume of circuitry required. Because of the slow date rates within the CC & S, it is feasible to employ circuits with very low-speed switching properties since these circuits would have lower power dissipation than similar faster circuits.

6.5 COMMAND DECODER

The Command Decoder, like the CC & S, is characterized by a large portion of digital circuits which can be implemented using microelectronic techniques. Those output commands which require a "floating control" are not suitable to microelectronics and hence should be implemented with standard techniques.

6.6 TV SUBSYSTEM PICTURE DATA AND CONTROL CHANNELS

Three areas can be readily implemented with microelectronics: (1) Programmer Matrix; (2) Accumulator; (3) Shift Register. Standard integrated circuits are presently available.

SECTION 7
TELEVISION

7.1 ENCOUNTER REQUIREMENTS

The feasibility of using Mariner-C or Advanced Mariner television subsystems for observing the nucleus during intercept has been determined on the basis of comet illuminance and TV sensitivity.

7.1.1 Comet Illuminance

The illuminance and angular subtense of the 3-sigma width for the nuclear condensation are shown as Figures 7-1 and 7-2 for Pons-Winnecke, based on the brightness model described in Volumes 2 and 5 [Cunningham, 1964]. Assuming for simplicity that the nuclear condensation is a uniformly bright source of brightness equal to the peak value, the source is also considered to be a square with sides equal to twice the 3σ value of the brightness distribution. For these assumptions Figure 7-1 represents the angular subtense of the assumed source, and the curve representeng peak illumination can be used as the illumination from the assumed uniform source. As the spacecraft approaches the comet, the illumination will increase. In fact,

$$I = I_o \, (d_o^2/d^2) \tag{7-1}$$

where

d_o = Reference distance = 1 A.U.

I_o = Illumination at d_o = 8.2×10^{-13} lumen/(cm^2)/(min of arc)^2

d = Actual distance (A.U.)

I = Illumination at d

Fig. 7-1 Angular Size (3-sigma) vs Comet Range for Pons-Winnecke

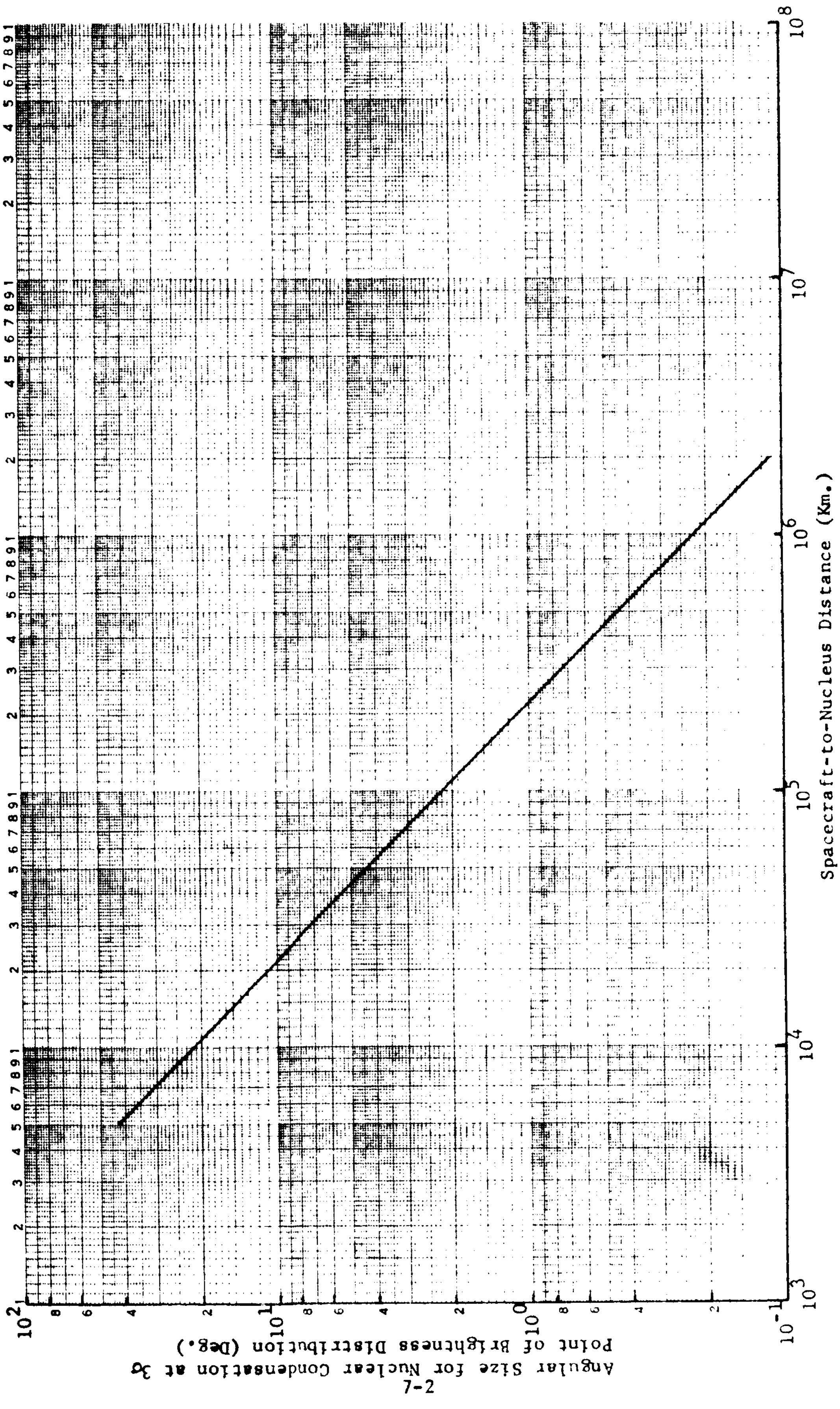
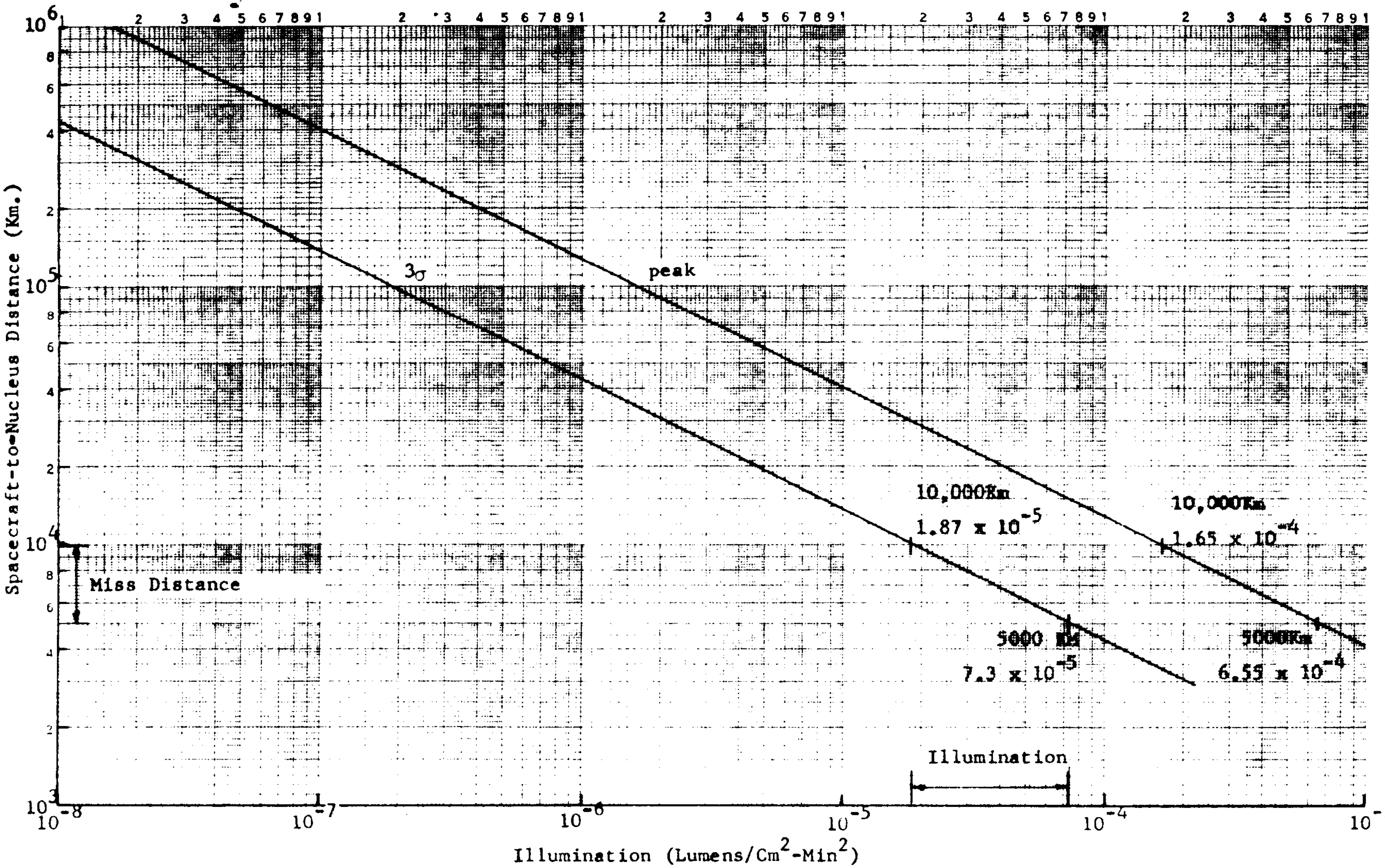


Fig. 7-2 Illumination vs Comet Range for Pons-Winnecke



The receiving optical system has a fixed field of view. Assuming that the angular subtense of the source is always equal to or greater than the field of view of the system, the surface area from which the system receives light decreases as the source is approached. Consequently, the total illuminance into the optics is a constant.

7.2 MARINER-C TV

Mariner-C TV characteristics are summarized below:

<u>TV Picture</u>	lines :	200
	elements :	200
	resolution :	2.5 km @ 19,000 km range
	kell factor :	0.7
<u>Detector</u>	0.0075 ft-candle-second at threshold S/N (filter losses not included)	
<u>Optics</u>	F/8 Cassegrain mirror system	
	focal length (f):	12 inches
	shutter time :	set at 0.25 sec (variable 0.1 to 0.5 sec)
	field of view :	1.05 by 1.05 deg. square

The flux density on the detector is

$$E = \frac{\pi}{4} I \, \theta_x \theta_y \, D^2 T \frac{1}{L^2} \quad (\text{lumens/cm}^2) \tag{7-2}$$

where

I = illuminance, (lumens/cm^2/min^2)

θ_x, θ_y = field-of-view angles = 63 min. of arc

D = diameter of entrance pupil $= \frac{f}{F} = \frac{12}{8}$ in = 3.8 cm

T = transmission efficiency of optics = 0.75

L = detector width (square detector) = 1.12 cm

Substituting,

$E = 2.21 \times 10^{-8}$ lumen/cm^2.

The sensitivity of the Mariner-C TV system is 0.0075 ft-candle-second with a shutter speed of 0.25 seconds or 0.03 ft-candle. Converting to flux density, the sensitivity is 3.33×10^{-5} lumen/cm^2.

7.3 ADVANCED MARINER TV

Advanced Mariner TV characteristics are summarized below:

<u>TV Picture</u>	lines :	400
	elements :	400
	resolution :	1 km at 10,000 km range
	kell factor :	0.7
<u>Detector</u>	0.0075 ft-candle-second/at threshold	
<u>Optics</u>	High-resolution system.	
	F/5.1	
	focal length	100 cm
	shutter time	40 millisec
	field of view:	1.51 x 1.51 deg. square

For these characteristics, the flux density is 1.21×10^{-6} lumen/cm^2.

As can be seen, the sensitivity of the Mariner-C system is three orders of magnitude greater than the illuminance of the comet nuclear condensation. The Advanced Mariner system is only one order of magnitude greater. Since its operating range of brightness levels is of the order of 100 to 1 and its shutter speed is set so high, the Advanced Mariner system could be used for viewing the comet.

SECTION 8
CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

Although Mariner-C hardware was considered as a starting point, several changes have been suggested where needed or where a marked improvement or advantage would result. Examples of this are

1. The use of a 25-watt amplifier to provide a higher transmission rate.

2. The use of a low-noise re-amplifier to provide not only a better command link margin but a more reliable system, since switching of antennas to the command receiver is not required. In addition, the system becomes independent of the Goldstone 100 kw transmitter since the system can now operate with the 10 kw transmitter at any station.

3. The recommendation to consider seriously the use of micrologic elements particularly in digital circuits. Although the communication system can be made without them, they will undoubtedly be used in the future in systems with greater requirements in terms of quantities of hardware and reliability.

Based on the study as summarized above, a potentially more reliable system than the Mariner 1964 design has been recommended for the Comet Probe consistent with 1970-1975 Spacecraft Technology.

8.2 RECOMMENDATIONS

Based on a consideration of future needs several areas are recommended for further study.

Section 6 and Appendix B detail the merits of using micrologic elements as opposed to discrete components in building both digital and analog circuits. New packaging techniques are discussed in particular for the S-band transponder. Reliability, weight, power and size will continue to place increasing requirements on the hardware. It is felt that the techniques discussed will help considerably in satisfying these demands.

Television is discussed in Section 7 to the extent of showing the characteristics required. It is suggested that before a science television system be included a more detailed analysis and comparision be made between the requirements and data collected by TV as compared to other instruments directed at the nucleus.

As space vehicles continue to probe deeper into space, it is becoming increasingly difficult to communicate the data required back to the Earth. Transmitter power is always limited by power generating capability, antenna size is limited by shroud dimensions and pointing accuracy, modulation efficiency is limited by the state of the art in hardware-implemented modulation techniques. Power generation equipment is discussed in Section 4. Active antenna pointing techniques were not found necessary for this study and therefore were not analysed. This will not be the case in all future systems. Coding techniques and detection of data by words rather than on a bit-by-bit basis must be looked into for increases in data transmission. Finally, a better technique of distributing the power between data and carrier must be found in order not to have excessive margins in the carrier tracking loop compared to the data link.

SECTION 9
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APPENDIX A

TELECOMMUNICATION SYSTEM ANASYSIS

A.1 INTRODUCTION

The analysis performed in this section derives the transmitter power requirements for the various links. In addition, the link capability (operating range, information capacity) is derived for several different system configurations.

Table A-1 List of Symbols Used

P_t = Total power available whether at the ground transmitter or vehicle transmitter as applicable to the particular situation

AP_t = Power in the carrier

BP_t = Power in the modulation

G_{tv} = Transmitting antenna gain on the vehicle

G_{rv} = Receiving antenna gain on the vehicle

G_{ts} = Transmitting antenna gain on the surface

G_{rs} = Receiving antenna gain on the surface

N = Total noise power, dbw

B = System bandwidth, cps

N/B = Noise density, dbw/cps

F = Receiver noise figure

$\frac{ST}{N/B} = \frac{\text{Signal Energy Per Bit}}{\text{Noise Density}}$

R_b = Transmitted bit rate

L_s = Space loss in dbw

$$= 37.8 + 20 \lg (\text{freq-mcps}) + 20 \lg (\text{distance-naut. miles}) \quad \text{(A-1)}$$

L_g = Losses in ground equipment

L_v = Losses in vehicle equipment

B_L = Phased-locked-loop noise bandwidth

B_{Lo} = Phased-locked-loop threshold noise bandwidth

α = Limiter suppression factor

$$= \frac{\text{Limiter output under conditions of noise}}{\text{Limiter output under no noise conditions}}$$

α_o = Limiter suppression factor at some specified S/N condition at limiter input specified as threshold.

$(\frac{S}{N})_{2B}$ = Signal to noise ratio assuming a bandwidth of 2B

T_{se} = Effective surface system temperature at output terminals of the antenna

T_v' = Vehicle antenna temperature

T_{ve} = Effective vehicle system temperature at output terminals of the receiving antenna

M = Link margin

A.2 Command Link

P_{t1} = 10 kw, or 40 dbw

P_{t2} = 100 kw, or 50 dbw

G_{ta1} = 51.5 $\pm$ 1.0 db for the 85 foot dish at 2115 Mc

$L_g = 0.5 \begin{pmatrix} -0.0 \\ +0.3 \end{pmatrix}$

L_v: The effects of this loss will be included in the calculation of N/B below.

A.2.1 Effective System Noise Temperature

$$T_{se} = T_s + (L_v - 1)\ T_o + (F-1)\ L_v\ T_o$$

$$= T_s + T_o\ (FL_v - 1)$$

Assume $T_s = 50^{o}K$ *

Assume $L_v = 0.9$ db

$$T_{se} = 50 + 290\ (1.23F-1),\ {}^{o}K \qquad \text{(A-2)}$$

$$\frac{N}{B} = KT_{se} = -228.6 + 10\ \lg T_{se}, \quad \text{dbw/cps} \qquad \text{(A-3)}$$

These two expressions are plotted in Figure A-1 for the possible range of noise figure values.

A.2.2 Carrier Power Requirements

The carrier power required can be established from the receiver phase-locked-loop characteristics. The calculations will be performed in terms of a modified form of the radar range equation. Expressed in db, it becomes

$$AP_{ts} + G_{ts} + G_{rv} - L_g - L_s - M = \left(\frac{S}{N}\right)_{2B_L} + 2BL + \frac{N}{B} \qquad \text{(A-4)}$$

$\frac{S}{N}_{2B_L}$ = S/N required in receiver phase-locked-loop bandwidth of $2B_L$,

This will be assumed 6 db, in which case the rms phase error will be 0.5 radian and the loop will remain in lock 99.7% of the time.

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*This is an estimate based on antenna temperatures by Giddis [1963].

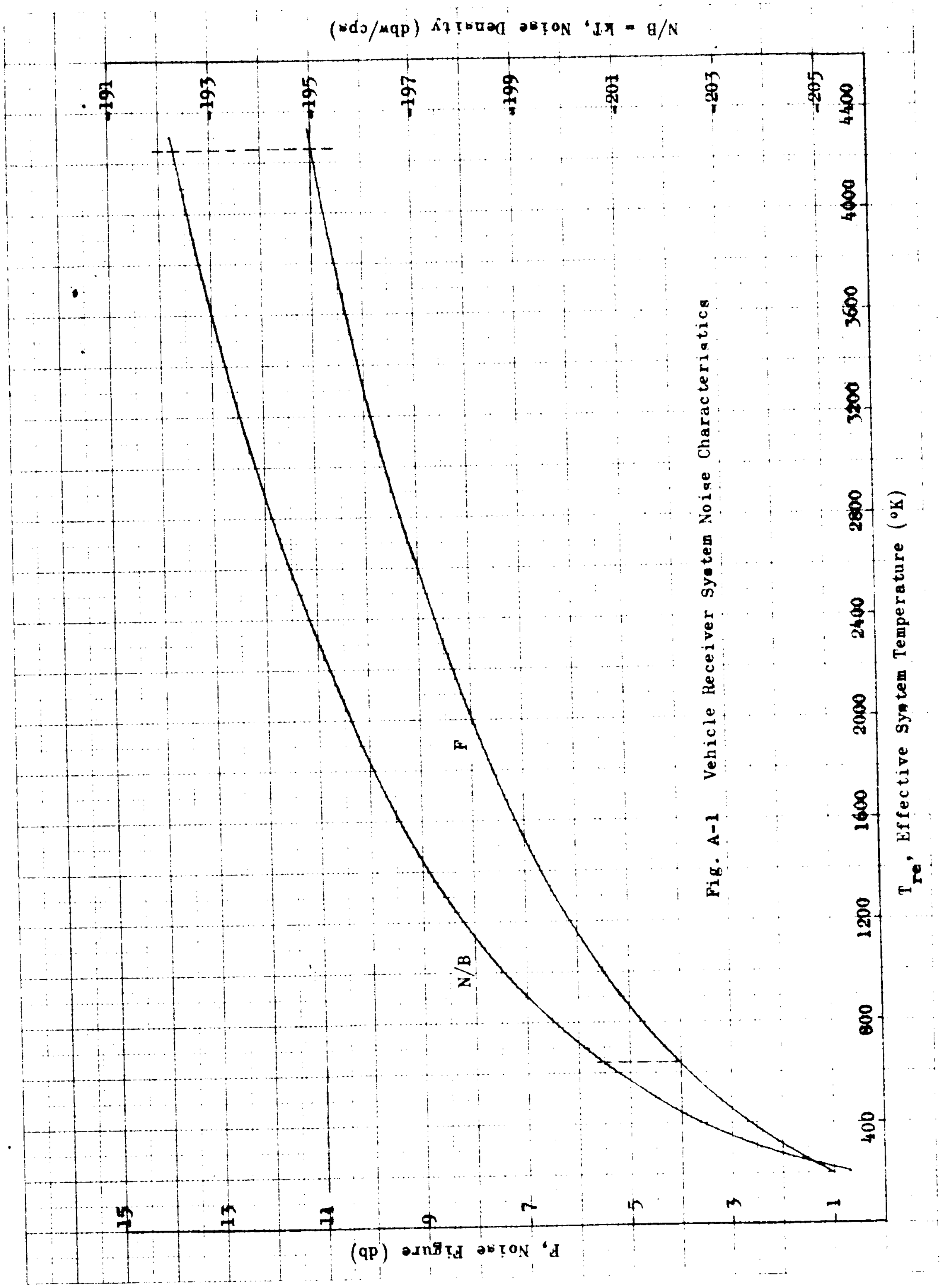

Fig. A-1 Vehicle Receiver System Noise Characteristics

$2B_L$ = Phase-locked-loop noise bandwidth at specified conditions. Threshold loop bandwidth equals 20 cps.

Since loop gain and therefore loop bandwidth increases with input S/N, a different bandwidth other than the $2B_{Lo}$ specified at threshold must be used. The increase in bandwidth will occur in a suppressed manner due to the bandpass limiter.

The effect can be calculated as a function of the limiter suppression factor α/α_o, given by:*

$$\frac{\alpha}{\alpha_o} = \sqrt{\frac{1 + \frac{4}{\pi}\left(\frac{N}{S}\right)_o}{1 + \frac{4}{\pi}\left(\frac{N}{S}\right)}} \qquad \text{(A-5)}$$

where $\left(\frac{N}{S}\right)_o$ = threshold $\frac{N}{S}$ in predetection bandwidth

$\frac{N}{S}$ = $\frac{N}{S}$ at operating conditions specified in prediction bandwidth

For 6 db S/N in the loop we obtain

$\frac{S/N}{(S/N)_0} = \frac{(N/S)_o}{N/S} = 4$, from which we obtain

$$\left(\frac{\alpha}{\alpha_o}\right)^2 \approx \frac{\frac{4}{\pi}\left(\frac{N}{S}\right)_o}{\frac{4}{\pi}\left(\frac{N}{S}\right)} \quad \text{or} \quad \frac{\alpha}{\alpha_o} \approx 2.$$

The operating bandwidth can then be found from

$$2B_L = \frac{2B_{Lo}}{3}\left(1 + 2\frac{\alpha}{\alpha_o}\right) = 33.3 \text{ cps or } 15.2 \text{ db-cps} \qquad \text{(A-6)}$$

*For the derivation of these expressions see Martin [1962].

Let L_s = 37.8 + 20 log f_{Mc} + 20 lg d (nautical miles)

or L_s = 223.5 + 20 lg d (millions of miles)

for f = 2115 Mc.

The required transmitter power and vehicle antenna gain can now be determined. Inserting the constants, Equation (A-4) **becomes:**

$$AP_{ts} + 51.5\ (\pm 1) + G_{rv} - 0.5\begin{pmatrix}+0.0\\-0.3\end{pmatrix} - 223.5 - 20\ \text{ld}\ d - M$$

$$= 6 + 15.2 + \frac{N}{B}\text{, d in millions of miles}$$

$$AP_{ts} + G_{rv} = \frac{N}{B} + M + 193.7\begin{pmatrix}-1.0\\+1.3\end{pmatrix} + 20\ \text{lg}\ d \qquad \text{(A-7)}$$

For a link margin, M, of 2db Equation (A-7) is plotted on Figure A-2 for the following conditions:

Curve a, F = 4 db, G_{rv} = - 6 db

Curve b, F = 11 db, G_{rv} = - 6 db

A.2.3 Command Link Modulation Power Requirements

The data rate for the JPL standard command system is 1 bps. The range equation for this case becomes,

$$BP_{ts} + G_{ts} + G_{rv} - L_g - L_s - M = \frac{ST}{N/B} + R_b + \frac{N}{B} \qquad \text{(A-8)}$$

Assuming the use of PN synchronized PSK/PM and inserting the constants, the general expression above becomes:*

* For R_b = 1 bps and $P_e = 10^{-6}$ the sync loop power requirements predominate and theoretically $\frac{ST}{N/B}$ = 13.5 db is required in a 1 cps bandwidth. However, based on the JPL Mariner-C specification MC-4-310A an $\frac{ST}{N/B}$ = 15.7 db must be provided to insure the performance characteristics therein defined.

$$BP_{ts} + 51.5\ (\pm 1) + G_{rv} - 0.5 \begin{pmatrix} +0.0 \\ -0.3 \end{pmatrix} - 223.5 - 20\ \lg d - 2$$

$$= 15.7(\pm 1) + 0 + N/B$$

$$BP_{ts} = 190.2 \begin{pmatrix} -2.0 \\ +2.3 \end{pmatrix} - G_{rv} + \frac{N}{B} + 20\ \lg d \qquad \text{(A-9)}$$

For a link margin of 2 db Equation (A-9) is plotted on Figure A-2 for the following conditions,

Curve c, $F = 4$ db, $G_{rv} = -6$ db

Curve d, $F = 11$ db, $G_{rv} = -6$ db

A.2.4 PN Ranging System Power Requirements

$$RP_{ts} + G_{ts} + G_{rv} - L_g - L_s - M = \left(\frac{S}{N}\right)_{2B_1} + 2B_L + \frac{N}{B} \qquad \text{(A-10)}$$

Assuming 12 db S/N required in a 1-cycle loop bandwidth this becomes,

$$RP_{ts} + 51.5\ (\pm 1.0) + G_{rv} = 0.5 \begin{pmatrix} +0.0 \\ -0.5 \end{pmatrix} - 223.5 - 20\ \lg d - 2$$

$$= 12 + 0 + \frac{N}{B}$$

$$RP_{ts} = 186.5 \begin{pmatrix} -1.0 \\ +1.3 \end{pmatrix} - G_{rv} + \frac{N}{B} + 20\ \lg d \qquad \text{(A-11)}$$

As may be seen, this differs from Equation (8) by - 1.5 db. Curves e and f of Figure A-2 represent Equation (A-11) as follows:

Curve e, $F = 4$ db, $G_{rv} = -6$ db

Curve f, $F = 11$ db, $G_{rv} = -6$ db

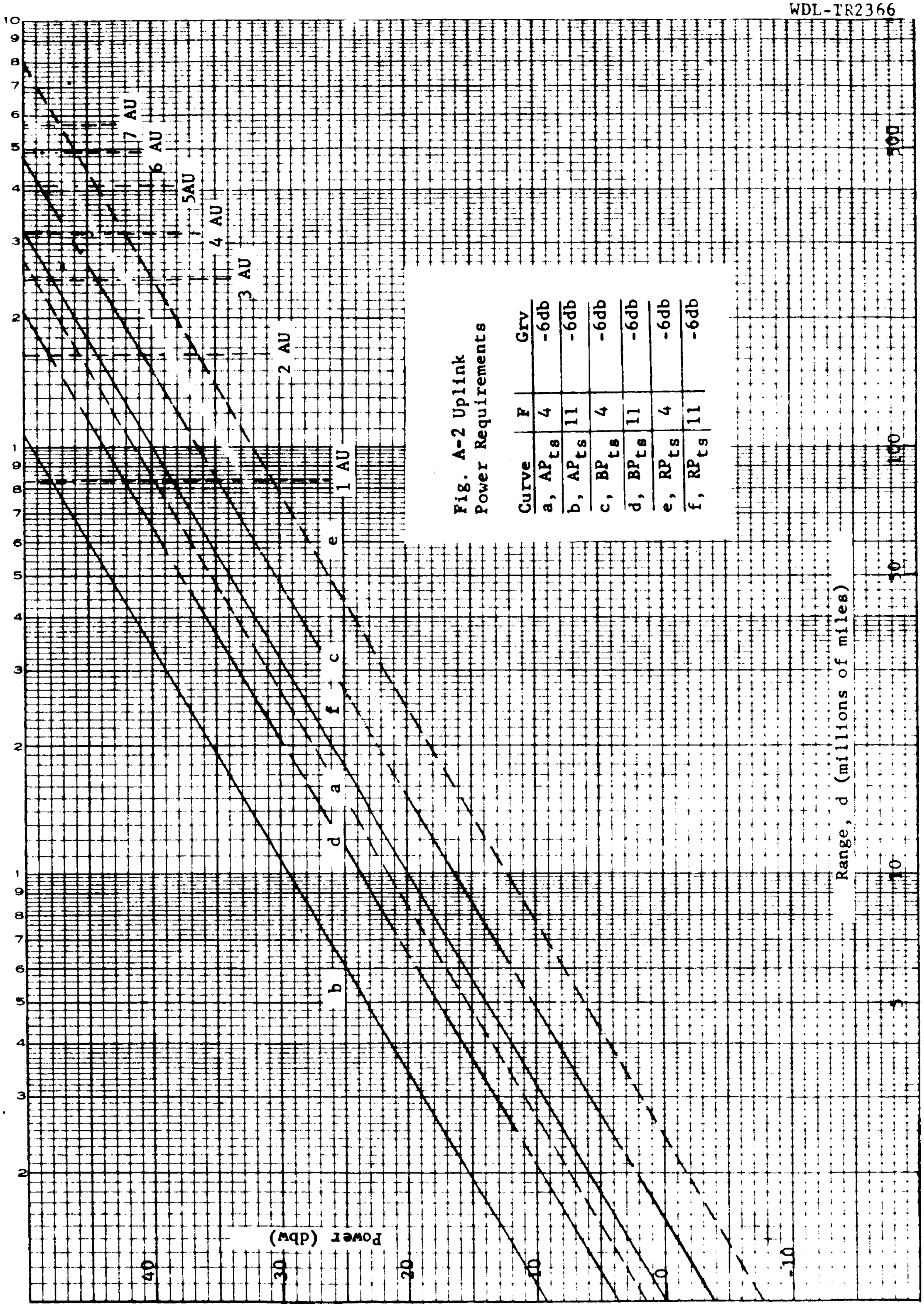

Fig. A-2 Uplink Power Requirements

Curve	F	Grv
a, AP_{ts}	4	-6db
b, AP_{ts}	11	-6db
c, BP_{ts}	4	-6db
d, BP_{ts}	11	-6db
e, RP_{ts}	4	-6db
f, RP_{ts}	11	-6db

A.2.5 Total System Power Requirements

From the above equations, it is seen that

$AP_{ts}: BP_{ts}: RP_{ts} = 8.5: 1.41: 1$

For F = 4 db it can be seen that a d = 3.3 A.U., or 270 x 10^6 miles

$AP_{ts} = 100$ kw

$BP_{ts} = 16.6$ kw

$RP_{ts} = 11.8$ kw

$P_{ts} = 128.4$ kw

The DSIF has both a 10kw and a 100kw transmitter available. For these two values of total power the operating ranges become:

$P_t = 10$ kw, $AP_{ts} = 7.8$ kw, d = 0.9 AU

$P_t = 100$ kw, $AP_{ts} = 78$ kw, d = 2.9 AU

This is summarized below including the case of F = 11 db.

P_t	F	Maximum Range
10 kw	4 db	0.9 AU, 74 x 10^6 miles
	11 db	.36 AU, 30 x 10^6 miles
100 kw	4 db	2.9 AU, 240 x 10^6 miles
	11 db	1.1 AU, 93 x 10^6 miles

A.3 TELEMETRY LINK

The power requirements for the telemetry link can be calculated. For this link the system constants are as follows:

G_{tv1} = 26.4 db, 4-foot dish within the Agena shroud

G_{tv2} = 30.3 db, 6-foot dish within the Centaur shroud

G_{rs1} = 53.0 $\begin{pmatrix}+1.0\\-0.5\end{pmatrix}$ db, 85 foot dish at 2295 Mc

G_{rs2} = 61.0 db, 210-foot dish at 2295 Mc

$L_v + L_g$ = line losses + polarization losses + tracking losses

= 2 db (± 1) assumed. 1 db each in the vehicle and on the ground.

L_s = $37.8 + 20 \lg f_{Mc} + 20 \lg d$ (nautical miles)

= $224.24 + 20 \lg d$ (millions of miles)

M = 2 db

$\left(\frac{N}{B}\right)_1 = KT_1 = 228.6 + 10 \lg 50$

= -211.6 dbw $\begin{pmatrix}+0.4\\-0.2\end{pmatrix}$, this assumes the use of the Maser preamplifier.

$\left(\frac{N}{B}\right)_2 = KT_2 = -228.6 + 10 \lg 250$

= -204.6 dbw $\begin{pmatrix}+0.8\\-1.0\end{pmatrix}$, this assumes the use of the parametric amplifier.

A.3.1 Carrier Power Requirements

Using Equation (A-4) and assuming the use of the 85-foot dish we obtain,

$$AP_{ts} + G_{tv} + G_{rs} - L_g - L_v - L_s - M = \left(\frac{S}{N}\right)_{2B_L} + 2B_L + \frac{N}{B} \qquad \text{(A-4)}$$

$$AP_{ts} + G_{tv} + 53.0 \begin{pmatrix}+1.0\\-0.5\end{pmatrix} - 2(\pm 1) - 224.24 - 20 \lg d - 2$$

$$= 6 + 2B_L + \frac{N}{B}$$

$$AP_{ts} = 181.24 \begin{pmatrix}-2.0\\+1.5\end{pmatrix} + 2B_L + \frac{N}{B} - G_{tv} + 20 \lg d$$

$2B_{Lo}$ = 12 cps, at $\left(\frac{S}{N}\right)_{2B_L}$ = 6 db and, by using Equations (A-5) and (A-6), we obtain

$2B_L$ = 20 cps or 13 db-cps.

$$AP_{ts} = 194.24 \begin{pmatrix} -2.0 \\ +1.5 \end{pmatrix} + \frac{N}{B} - G_{tv} + 20 \lg d \qquad \text{(A-12)}$$

Equation (11) is plotted on Figure A-3 for the following conditions:

Curve (a), 4 foot dish on the vehicle and 250°K surface equivalent system temperature.

Curve (b), 4 foot dish and 50°K temperature.

For the case of the six-foot dish the required power drops by 3.9 db at any particular range.

A.3.2 Ranging Power Requirements

$$RP_{ts} + G_{tv} + G_{rs} - L_g - L_v - L_s - M = \left(\frac{S}{N}\right)_{2B_L} + 2B_L + \frac{N}{B} \qquad \text{(A-10)}$$

$$RP_{ts} + G_{tv} + 53.0 \begin{pmatrix} +1.0 \\ -0.5 \end{pmatrix} - 2(\pm 1) - 224.24 - 20 \lg d - 2$$

$$= 12 + 0 + \frac{N}{B}$$

$$RP_{ts} = 187.24 \begin{pmatrix} -2.0 \\ +1.5 \end{pmatrix} + \frac{N}{B} - G_{tv} + 20 \lg d \qquad \text{(A-13)}$$

Since Equation (A-13) is identical to Equation (A-10) minus 7db, i.e., $RP_{ts} = AP_{ts}$ - 7 db, curves (a) and (b) of Figure A-2 can be interpreted as RP_{ts} + 7 db. For the case of the six foot antenna, the required power drops by 3.9 db at any point.

Tables A-2 and A-3 present a comparison of the various system configurations both in terms of operating range and bit rate for various configurations.

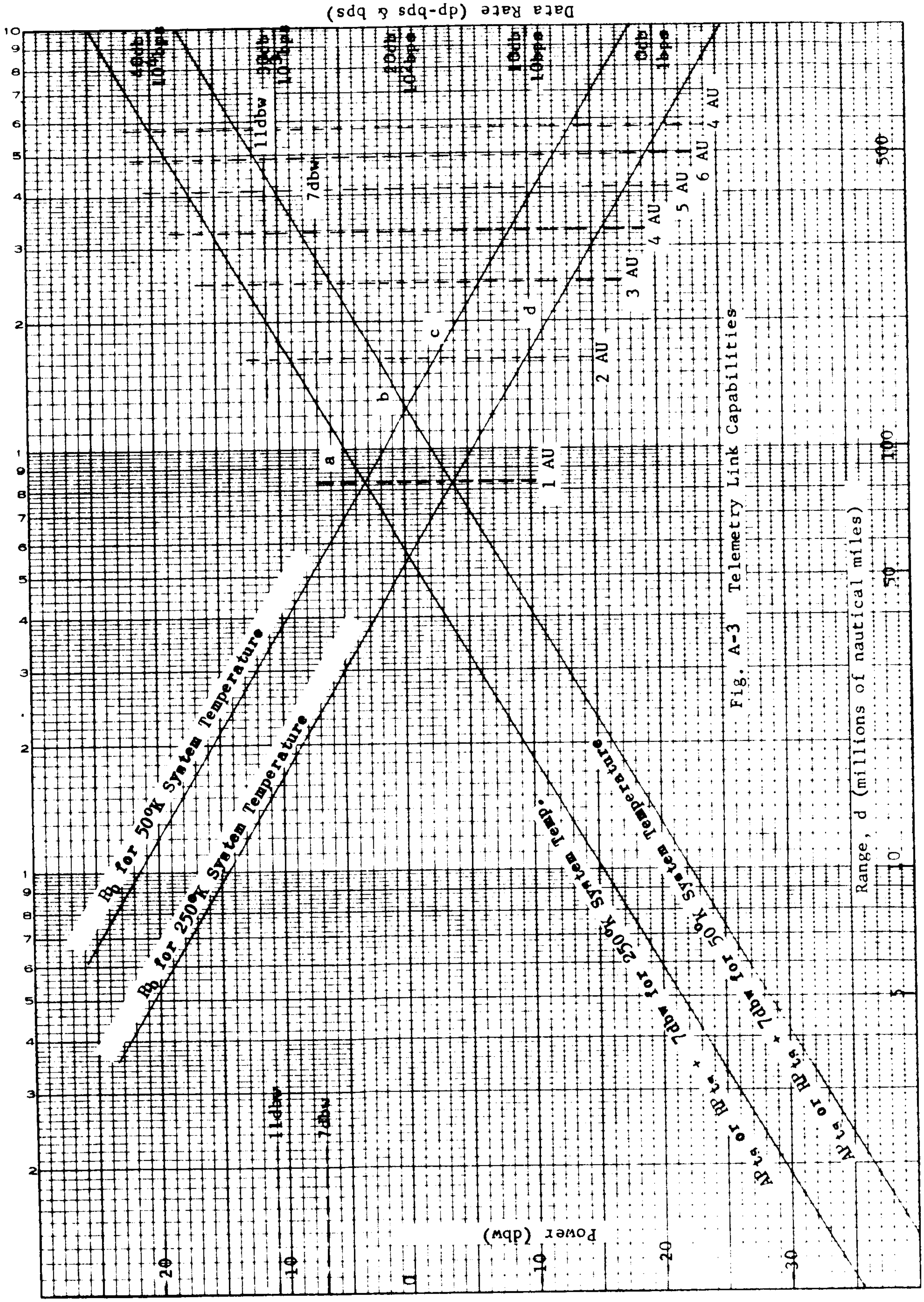

Fig. A-3 Telemetry Link Capabilities

EUGENE DIETZGEN CO.
MADE IN U. S. A.

NO. 340R-L310 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH

Table A-2 Command Link Capabilities

Transmitter (dbw)	Receiver Noise Figure (db)	Vehicle Antenna Gain (db)	Range (millions of miles)	A.U.
40	11	-6	35	0.42
		0	70	0.85
	4	-6	100	1.2
		0	200	2.4
50	11	-6	106	1.3
		0	212	2.6
	4	-6	207	2.5
		0	414	5.0

Table A-3 Telemetry Link Capabilities

Vehicle Antenna	Power Output (Watts)	System Temperature (^oK)	Maximum Range (Miles)	Data Rate (bps) (at Max. Range)	(at 1.5 A.U.)	(at 0.26 A.U.)
4-Foot Dish	10	50	290×10^6 3.5 A.U.	11	100	3000
		250	130×10^6 1.6 A.U.	2.2	20	600
	25	50	450×10^6 5.5 A.U.	11	250	7500
		250	200×10^6 2.4 A.U.	2.2	50	1500
6-Foot Dish	10	50	450×10^6 5.5 A.U.	11	250	7500
		250	200×10^6 2.4 A.U.	2.2	50	1500
	25	50	720×10^6 8.75 A.U.	11	630	18750
		250	330×10^6 4.0 A.U.	2.2	126	3750

A.3.3 Telemetry Modulation Power Requirements

Rather than calculate the required power for a particular bit rate, a particular power will be assumed and the recoverable bit rate for all distances will be determined. Two transmitter power outputs will be assumed $P_{tv1} = 10$ watts and $P_{tv2} = 25$ watts. Assuming a maximum of 3 db* of the power transmitable as modulation, the modulation power becomes $BP_{t1} = 5$ watts, or 7 dbw, and $BP_{t2} = 12.5$ watts or 11 dbw. Equation (A-8) is used as follows:

$$BP_t + G_{tv} = G_{rs} - L_g - L_v - L_s - M = \frac{ST}{N/B} + R_b + \frac{N}{B} \qquad \text{(A-8)}$$

The bit error is assumed to be $P_e = 10^{-3}$, for which $\frac{ST}{N/B} = 8.2$ db including hardware inefficiency.

$$BP_t + G_{tv} + 53.0\begin{pmatrix}+1.0\\-0.5\end{pmatrix} - 2(\pm 1) = 224.24 - 20 \lg d - 2$$

$$= 8.2 + R_b + \frac{N}{B}$$

$$R_b = -183.44\begin{pmatrix}+2.0\\-1.5\end{pmatrix} + BP_t + G_{tv} - \frac{N}{B} - 20 \lg d \qquad \text{(A-14)}$$

Equation (A-14) is plotted on Figure A-3 for the following conditions:

Curve c: $BP_t = 7$ dbw, $G_{tv} = 26.4$ db, $\frac{N}{B} = -211.6\begin{pmatrix}+0.4\\-0.3\end{pmatrix}$

Curve d: $BP_t = 7$ dbw, $G_{tv} = 26.4$ db, $\frac{N}{B} = -204.6\begin{pmatrix}+0.8\\-1.0\end{pmatrix}$

If the six-foot antenna had been assumed the achievable R_b would increase by 3.9 db for both curves. If a 25-watt amplifier were assumed the R_b would increase by 4 db for both curves.

*This distribution of the power provides the most efficient utilization of total power if 3 db of the power are required for the carrier. If the carrier does not require this much power, more power can be made available to the modulation although the overall efficiency of power utilization will drop. For a detail discussion of this, see Martin [1962] and Giacolleto [1947].

APPENDIX B
MICROELECTRONICS

B.1 ADVANTAGES OF MICROELECTRONICS

Microelectronics can offer the following advantages:

1. Reduction of Weight
2. Reduction of Volume
3. Increased Reliability
4. Reduction of Costs

B.1.1 Weight and Volume

The reasons for the reduction of weight and volume are quite evident. For digital systems reduction of weight and volumes up to 80% can be achieved.

B.1.2 Reliability

The increase in reliability is especially notable for digital circuits. Within the recent months excellent reporting on device reliability has been offered by the different companies making integrated circuits. It has been said that the reliability of the complete circuit (flip-flop, and gate, etc.) can eventually approach the reliability of a single transistor.

B.1.3 Costs

The possible reduction of costs associated with microelectronics is not so evident. The continued reduction of device cost is certainly a factor.

Another large factor is the reduction of design and testing costs since the purchased device is usually a complete circuit. Also a factor that will eventually contribute to a lower cost in the manpower savings in the fabrication (packaging) area. This is primarily due to the fact that the fabrication on the circuit level is eliminated.

B.2 MICROELECTRONIC TYPES

B.2.1 Microelectronic Circuit Types

The different sets of terminology and definitions associated with microelectronics are, th the best, no less than the number of participating companies in the microelectronic field. However, regardless of manufacturers and customers terminology and defintions of microelectronics, a general classification of microelectronic circuit types can be made. This results in the following three subsets of microelectronic circuit types.

1. Micromodule Circuits
2. Thin Film Circuits
3. Integrated Solid Silicon Circuits

Micromodule Circuits

Ultra small but discrete components interconnected by any of a number of methods (wires, thin films, conductive cement, etc.) and packaged in extremely small modules. This is an extension of past techniques and should not be unfamiliar to the reader.

Thin Film Circuits

Circuits on an unactive substrate where the passive thin film elements (R, C, L) are produced by such electrochemical processes as vacuum deposition, photoengraving, anodization, and evaporation. The active elements are discrete and deposited, usually being built up on a silicon substrate.

Integrated Solid Silicon Circuitry

Circuits on a silicon substrate where both passive and active elements are formed by photoengraving, diffusion, evaporation, and alloying of selected regions of the silicon crystal.

B.2.2 Merits of Different Microelectronic Circuit Types

In an effort to describe the relative merit of the three types of microelectronic circuits (micromodule, solid silicon, and thin film) the following important parameters are utilized:

1. Circuit Flexibility
2. Circuit Performance
3. Reliability
4. Power Consumption
5. Size
6. Cost

The order in which the parameters are listed is deliberate since each parameter on the list should be satisfactory before the next listed parameter can be considered.

Circuit Flexibility

Micromodule circuitry provides the most circuit flexibility. This is obvious since lumped circuit parameters of any value (active and passive) can be used. Thin film circuitry although not having the flexibility of micromodule circuitry certainly has more flexibility than solid silicon circuitry. Prime reasons for this are:

1. Thin film resistors and capacitors have a larger range of values than solid silicon resistors and capacitors.
2. Thin film resistors and capacitors have tighter tolerances than solid silicon resistors and capacitors.

Circuit Performance

Again with its choice of component values and tolerance micromodule circuits have the best circuit performance. Since the thin film circuitry is more flexible than solid silicon, better circuit performance should be obtained from thin film circuits.

Reliability

A carefully constructed solid silicon device should have better reliability than either thin film or micromodule devices. Depending upon the construction of the interconnect and bonding, the thin film devices should have a better reliability than micromodule devices.

Power Consumption

Circuits that offer the best flexibility, component tolerances, and component ranges should offer the lowest power consumption. Hence, we have in order micromodule, thin film, and solid silicon.

Size

By the nature of the basic constructions, the order of least size is solid silicon, thin film, and micromodule. However, the average size difference between solid silicon and thin film is relatively unimportant.

Cost

For small quantities of identical curcuits microelectronics is very costly. For the small lot, the solid silicon circuitry would be the most costly.

Thin film circuitry on the average would be more costly for small lots than would be micromodule circuitry. However, when the lot becomes very large, solid silicon would become the least costly, thin film next, and then micromodule.

Digital circuits are usually produced as a standard compatible set with widespread usage. This implies a large production which is favorable to solid silicon from a cost factor. The flexibility of component selection and tolerances of most digital circuits usually is not a stringent problem. Reliability and size is an advantage of solid silicon over both thin film and micromodule circuitry. Also, the power consumption in the medium speed range for digital circuits is not too different for the three types of microelectronic circuits. Hence, the solid silicon position for digital circuits is very favorable.

For analog circuitry of large complexity and small production, micromodule circuits have a decided advantage because of circuit flexibility and circuit performance. For analog circuits of small complexity, the reliability and size of thin film circuitry can make its usage advantageous. Because of tolerance and restricted component ranges, it appears that solid silicon circuitry must be restricted to extremely uncomplicated circuitry.

B.2.3 Different Microelectric Types

The majority of the semiconductor companies are now marketing microelectronics. The greater percentage of these devices are solid silicon digital circuits. A partial list of these companies and a description of their devices is given in Table B-1. Most of the logic circuits fall into the following classes:

TABLE B-1 Survey of Microelectronics Devices

MANUFACTURER	TYPES OF CIRCUITS	DIGITAL	TYPICAL COST SAMPLES	SPEED OR DELAY OF DIGITAL CURCUITS	POWER REQD FOR GATE OR F-F	LINEAR	PACKAGE CONFIG-URATION	LITERA-TURE AVAIL.	RELIA DATA AVAIL	REMARKS
AMELCO, INC. (Mt. View, California)	1. Digital - DCTL 2. Custom analog & digital circuits, DTL - partial line; Single Chip	1. Gate 2. RS Flip-Flop 3. Buffer 4. ½ Shift Register 5. Half Adder	$25 $30	30 nsec/gate 50 nsec/½ shift register	15 mw 3.5mw/FF 2mw/gate	Custom Diff. Amps.	TO-5 Flat-Pak	Yes	Yes	
FAIRCHILD SEMI-CONDUCTOR (Palo Alto, California)	1. Digital - DCTL-DTL 2. Custom analog & digital circuits; "Micrologic"	Complete digital line	RTL 25-100: $21 DTL 25-100: $20-50	50 nsec 70 nsec DTL 10 Kc	15mw/node Low Power Micrologic II 3mv/node	DC Amp. and Custom; Full analog line	TO-5 TO-47 Flat-Pak	Yes	Yes	
GENERAL ELECTRIC (Hicksville, New York)		DISCONTINUED ALL INTEGRATED CIRCUITS								Coming out with a new line in 1965.
GENERAL MICRO ELECTRONICS (Sunnyvale, California)	1. DTL-T^2L-RTL	Complete digital line	N.A.	10 Mc	4mw/gate 16mw/FF.	Custom	TO-5 or Flat-Pak	Yes	No	
MOTOROLA (Phoenix, Arizona)	1. Digital - MECL-DTL 2. Custom analog circuit "unilogic"; Single Chip	Complete digital line	MECL 25-100: $17 DTL25-100: $18	3-5 nsec delay/stage	35mw/gate	Complete analog line	TO-5 Flat-Pak	Yes	Yes	Second-sourcing Signetics, on DTL type
RAYTHEON (Waltham, Massachusetts)	1. Digital - RTL-DTL; Single Chip	Complete line available in 1965	1-24: $25 100-999: $16	25 nsec	RTL - 4mw/gate	Custom	TO-5 or Flat-Pak	Yes	No	Second-sourcing Signetics digital line
RCA (Somerville, New Jersey)	1. Digital - DTL; Multi-chip	1. Gate	$14	12 nsec	14mw/gate		TO-5	Yes	No	Plans to release a new logic family using FETS
SIGNETICS (Sunnyvale, California)	1. Digital - DTL 2. Custom analog ckt "ILE"; Single Chip	Complete digital line including one-shot multivibrator; extended line more functions per chip	1-25: $22 100-249: $20	25 nsec/gate 10 Mc/Flip-flop	3mw/gate 10mw/FF	1. DC Amp 2. AC Amp. Custom	TO-5 or Flat-Pak	Yes	Yes	Expanding their facility Have a limited temp. range circuit with reduced price
SILICONIX (Sunnyvale, California)	1. Digital - DTL 2. Developing low level switches, Single Chip	Full digital line	1-999: $20	12 nsec/gate 15 mw 10 mc clock rate 18 nsec/gate	15 mw 7 mw	Custom; Developing Analog Line	TO-5 Flat-Pak TO-18	Yes	Yes	
SYLVANIA (Woburn, Massachusetts)	1. Digital -T^2L; Single Chip	1. Gate 2. Flip-Flop RS	$25 1-24: $80 1-100: $65	10 nsec 20 Mc	15mw/gate		TO-5 Flat-Pak	Yes	Yes	Working on DTL line
TEXAS INSTRUMENTS (Dallas, Texas)	1. Digital -RCTL 2. Analog circuits "Solid Circuit"; Single Chip	Complete digital line 51 series and 53 series	25-249 '51'-$25 '53'-$2[illegible]	500 kc. '51' [illegible] '53'	3mw/gate 6mw/FF 5mw/gate 22mw/FF	1. DC Amp 2. AC Amp. Custom and 52 series	TI Std welded Flat-Pak	Yes	Yes	2-week delivery on 51 and 53 series
WESTINGHOUSE (Youngwood, Pa.)	1. Digital - DCTL-DTL 2. Analog circuits "FEB"; Single Chip	Complete digital line	$[illegible]	20 nsec/gate [illegible] RS FF	10mw/gate 24mw/RS FF	1. AC Amp. 2 2 DC Amp 3. Video Amp. 4. Audio Amp. 5. Oscillators 6. Mixer 7. IF amp	Flat-Pak or TO-	Yes	Yes	Second-sourcing Signetics

1. Resistor coupled logic (RTL)
2. Diode coupled logic (DTL)
3. Emitter coupled logic (ECL)
4. Transistor-Emitter coupled logic

Many companies offer two or more of the above basic types. It appears, however, that Diode Coupled logic is becoming the most widely used of the four basic types. This type of logic is characterized by medium power dissipation, good switching speed (on the order of 25-40 nanoseconds which result in switching speeds of one to five megacycles), and good noise immunity.

Emitter coupled logic fabricated with small area transistors offer tremendous speed advantages (rise and fall times could be as low as 15 nanoseconds). The primary reason for the speed is that the transistors operate in the non-saturating mode. Examples of the various types of logic are given below:

1.	Resistor-coupled logic	TI Series 51 Fairchild Micrologic Fairchild Millawatt logic
2.	Diode-coupled logic	Signetics Series SE Fairchild DTL Series
3.	Emitter-Coupled logic	Motorola MECL Series
4.	Transistor-Emitter Coupled logic	PSI PCG Series